Evaluating profitability of solid timber production from 15 year old pruned and thinned *Eucalyptus nitens* (Deane & Maiden) in Canterbury

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A thesis submitted in fulfilment of the requirements for the

Degree of Master of Forestry Science

at the School of Forestry, University of Canterbury

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May 2015

Abstract

This case study investigated profitability of a small stand of fast-grown *Eucalyptus nitens* in Canterbury for sawn timber production. This stand was pruned and thinned and then harvested at 15 years old. An estimate of per-hectare log yields and diameters was made from the stand. Sample logs were sawn, dried and profiled, then products quantified. Log prices were estimated using the residual value method. Prices were summed for sawn products from each log, from which processing expenses and sawmill profit were deducted for an estimate of log value. In the absence of market prices for sawn *E. nitens* products empirical estimates of price were derived from market survey data. Predictive models were produced from estimated stand log yields along with predicted product revenues and processing costs from sample logs. These were used for estimating per-hectare log residual values from the case study stand trees. Financial returns to the grower were then calculated as discounted cash flows from the estimated log residual values per hectare, taking into account grower costs along with harvesting and transport costs. Best-practice processing methods were identified from the literature and applied as a productivity benchmark. Methods were developed with the view to standardising data across research efforts that seek to improve grade recoveries for *E. nitens*. A range of factors were investigated that potentially influenced *E. nitens* log residual value in this case study, including log diameter and log position. Outcomes included a reasonably favourable return on investment for the grower. However, this depended on a number of factors such as land price, distance from processor, product prices, grading methods, drying methods and level of sawmill profit. The application of contemporary best practice small-scale processing methods indicates that *E. nitens* has potential as a profitable plantation species for solid timber production.

Acknowledgements

Firstly I would like to sincerely thank John Fairweather for his faith in me to be able to complete this project. John provided the initial encouragement to embark on this project, he supported me all the way through with his time, his advice, his feedback, his friendship, his logs, his equipment and anything else I required. This project would not have happened without him and his wonderful wife Robyn.

Many thanks to the staff at the School of Forestry at Canterbury University and my supervisors David Evison and Euan Mason.

A special thanks to SCFNZ Ltd for their generous scholarship that allowed me to undertake this study full time.

I would like to acknowledge and thank those who provided me support and advice, including John Moore, Mark Bloomberg, James Turner, Bruce Manley, Doug Gaunt, Heidi Dungey, Trevor Innes and Robin Curtis.

Lastly I would like to give special thanks to my partner Ruth who has been supportive and forgiving and held my family together while I completed this thesis.

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Chapter 1
Introduction

1.1 Introduction

This study examines the economic viability of growing *Eucalyptus nitens* for solid timber products using discounted cash flow analysis. Because *E. nitens* has not been processed or marketed in New Zealand to date the approach was to value sawlogs based on residual value to the grower, which involves subtracting processing costs from sawn timber revenues.

A small stand of pruned and thinned 15-year-old trees was available in Canterbury for harvesting, as was a small-scale processing operation that was recently set up specifically for processing eucalypt for solid timber. This provided the opportunity for assessing revenues and expenditures as a case study to estimate profit to the grower.

1.2 Background

Eucalyptus nitens is a fast growing and cold-hardy eucalypt species grown in cooler regions of New Zealand (McKenzie, Turner, & Shelbourne, 2003, p. 63). The species is commonly found on farms and in small plantations throughout rural Canterbury, Otago and Southland, with some stands pruned in anticipation of solid timber processing. The Southland Plantation Forest Company Ltd has established approximately 10,000 hectares of *E. nitens* in Southland for hardwood chip/fibre. *E. nitens* is considered to be a well-suited plantation eucalypt species for cooler climates because of frost tolerance, and good growth and form (Beadle et al., 2008, p. 46; Washusen et al., 2008, p. 4).

E. nitens is being managed for solid timber production in other countries, with approximately 30,000 hectares of Tasmania's eucalypt plantations (primarily *E. nitens* and *E. globulus*) being pruned and thinned (Washusen, 2011) in anticipation of processing of solid timber products. In Chile pruning and thinning of *E. nitens* is also a common practice (Beadle et al., 2008, p. 46), with approximately 25,000 hectares being pruned and thinned for solid timber production (Valencia, 2014).

Pinus radiata is the dominant plantation forestry species grown in New Zealand with 90% of the plantation forest area in this species, followed by Douglas fir holding 6% of the plantation forest area (NEFD 2011). There may be a case for diversifying plantation timber species to reduce risk (Nolan, Greaves, Washusen, Parsons, & Jennings, 2005, p. 83). Species diversification may also provide specialty forest products that are quality differentiated and additional to those being currently produced from radiata pine, with opportunities both for export and import substitution that could improve the total revenue produced from forest products.

E. nitens timber has good strength properties and appearance characteristics, but is considered to be very difficult to saw and season. If *E. nitens* were to yield adequate recoveries of good quality solid-wood products this species could earn a wider role in New Zealand plantation forestry (McKenzie et al., 2003, p. 64). Published studies to date have demonstrated low sawn timber grade-recoveries from the species.

It is well known that investors are cautious of start up forest industries (Nolan et al., 2005, p. 83). Because plantation forestry involves longer time frames than other crops, investors would require a comparatively higher level of confidence in projected returns from forest plantation ventures before considering commitment of capital, especially for ‘emerging’ species lacking a solid history of production, improvement and research.

Hardwood products are mostly imported into New Zealand with negligible domestic production. Historically, hardwood products sourced from old-growth tropical rainforests have been abundant and inexpensive. With chain of custody, legality and sustainability certification of forest products now common practice, assurance of supply and stability of prices are uncertain for hardwood products from old growth and tropical forest origin.

For an industry to develop around plantation hardwood products, log values must reflect both an adequate return to the grower, along with product returns that both cover the costs of production and generate a profit (Nolan et al., 2005, p. 83). Serious growers and investors who would develop an industry of a size that takes advantage of scale efficiencies would require some knowledge of expected returns, even if only returns from operating at a scale in proportion to an emerging industry.

1.3 Research Problem and Objectives

Because of serious processing degrade of sawn timber products, profitability has not been adequately demonstrated to date from growing *E. nitens* for solid timber.

The objective was to assess economic returns to the tree grower for 15 year-old *E. nitens* that were pruned and thinned, using best practice contemporary processing methods.

To achieve this overall research objective it was necessary to also examine stand characteristics, wood processing costs, sawn timber grade recoveries, product pricing, novel products and wood degrade issues. Contemporary best practice processing methods using small-scale processing equipment were applied in an attempt to produce grade recoveries sufficient for a profit to the grower.

1.3.1 Research questions

For 15 year old case study *E. nitens*:

1. What are the financial returns to the grower?

2. What factors determine financial returns to the grower?

3. What methods are needed to best estimate financial returns to the grower?

1.4 Conclusions

This study documented the economic viability of growing *E. nitens* for solid timber production from a small stand of trees near Rangiora, Canterbury. A range of issues have limited the success of processing *E. nitens* into sawn appearance products to date. If quality sawn appearance products could be produced in sufficient quantities and at a reasonable cost, the opportunity could emerge for profitably growing *E. nitens* for solid timber production. The challenge for processing *E. nitens* is to minimise costs and maximise sawn production while also minimising degrade. The challenge for growing *E. nitens* is to produce logs that yield the highest sawn timber value per hectare.

The literature review will examine the trade-offs and issues with processing *E. nitens* and log issues that influence the returns generated from production of sawn timber.

Readers are advised that there is a glossary of terms in Appendix E.

Chapter 2
Literature Review: Estimating the profitability of growing *E. nitens*

2.1 Introduction

This study aimed to estimate the profitability of growing *E. nitens* for solid timber products as a case study using discounted cash flow analysis. Discounted cash flow analysis is based on the theory of compound interest and brings all future costs and revenues into the present by adjusting these to take into account interest over the number of years required for the cost or revenue to be realised (Brown, 2000, p. 54). Discounted cash flow analysis is generally recognised as the accepted method of forest valuation in New Zealand (Bloomberg, Bigsby, & Sedcole, 2002, p. 27).

Estimating profitability requires pricing of logs and trees. A method commonly used for appraising log values is the residual value method (Fairfax & Yale, 1987, p. 125). The residual value method requires price estimates for final products and deducts processing costs and required profits to determine the residual log price (Fairfax & Yale, 1987, p. 125; Liggett, 1995, p. 84). This price represents the maximum amount the sawmill would pay for the log (Mbugua, 2003, p. 24).

The residual value approach has been used since the turn of the 20th century in Western U.S.A. for appraisal of log values (Fairfax & Yale, 1987, p. 125). Historically U.S.A. Forest Service appraisals involved estimating sales value of timber products from a price index of past sales (Fairfax & Yale, 1987, p. 125), with gross product values determined by the grade volumes multiplied by the lumber prices (Nagubadi, Fight, & Barbour, 2003, p. 2). Transactional evidence is now favoured over residual value methods in the U.S.A. for valuing logs of species where comparable sales data for logs is available (Nagubadi et al., 2003, p. 1).

In New Zealand, the residual value method has been used for calculating radiata pine log grade prices that were used to explain regional variation in sawlog prices according to their attributes (Bloomberg et al., 2002). In Australia, Innes at al. estimated log values for plantation *E. nitens* using the residual value method (Innes, Greaves, Nolan, & Washusen, 2008).

Neither log price data, nor product sales price data for sawn products is available for *E. nitens* in New Zealand. In the absence of sales price data, alternative methods were required to price sawn timber products for determining log residual value. This chapter describes methods for estimating prices in the absence of market data.

In addition to sawn timber product values, it is necessary to consider other factors which affect *E. nitens* log residual value. Residual value is directly influenced by processing costs and, by its nature, the process of producing sawn timber involves many steps and outcomes can vary. It is important to consider the nature of timber processing in order to assess how best to maximise residual value. Important factors affecting log residual value are the quality of the sawn wood products as grade recoveries, the volumes of sawn timber produced and the costs involved in production of these. Grade recoveries are influenced by silviculture, log position, log diameter and sawmilling methods. Sawn volumes and costs are influenced by log diameter, log length and sawmilling methods. Each of these factors is considered. First, however, attention is given to the application of residual value methods to *E. nitens*.

2.1.1 Studies of *E. nitens* residual value

There are clear inconsistencies between production, grading and pricing methods used in contemporary studies that sought to quantify levels of defect, degrade and product recoveries for *E. nitens* sawn timber in order to estimate log residual value. The need for relevant research was identified by Nolan et al. (2005, p. v) when they made recommendations for improving production efficiency for sawn *E. nitens*, stating:

> Work in these areas should be deliberate comparative studies, operating across species to a standard methodology that integrates growing and milling results, and provides improved assessment data for plantation inventory and economic modeling.

There have been subsequent studies on this topic but they have not met the standards recommended by Nolan et al.

Innes et al. (2008) assessed product recoveries from three production methods in order to estimate log residual values for *E. nitens*. However, the three production methods could not be adequately compared because grading methods, green sawn thickness, product values and methods for quantifying defect and degrade all differed between them. Furthermore, pricing of timber products was based on assumptions that were arbitrary, producing an average log value delivered to the sawmill of only A $72.37 per cubic metre. The conclusion that growing and processing thinned and pruned *E. nitens* was uneconomic may have resulted from both poor study design and poor application of grading and pricing methods that led to underestimating log revenues, discussed in more detail below.

Although this study compared returns from three processing methods, grading was not consistent between processing methods (Innes et al., 2008, p. 8). Only one method (Gunns Lindsay Street) produced straightened and machined final products for grading while another method (ITC Newood) did not allow for edge distortion, thus artificially elevating the recovery results for this method (Innes et al., 2008, p. 19). ITC Newood boards were not edged, but board faces were dressed to final product thickness for grading. In the third method (ITC Heyfield) dry boards were edged but faces were only skim dressed. These skim dressed boards were then assessed for surface checking to determine product value, despite acknowledgement that this has lower accuracy compared with grading final products (Innes et al., 2008, p. vi). This is because skip and other sizing defects are difficult to accurately assess and grade for until boards are sized to final product dimensions. Furthermore, dressing to final product dimensions exposes measurable levels of internal checking to the board surface for grading, beyond those exposed during skim dressing. Innes et al. (2008, p. 10) then downgraded select and medium-feature boards to high-feature grade in proportion to observed levels of internal checking for the two methods that involved dressing board faces to final product thickness. However, such downgrading was not undertaken on the technique involving skim-dressing board faces because an assessment of internal checking was not made. It was not explained why levels of checking from the two methods where board faces were dressed to final product thickness were artificially elevated according to levels of internal checking. It could be argued that the apparently arbitrary allowance given for internal checking would have had an unnecessarily high negative impact on grade recoveries from these two processing methods, despite this allowance being described by Innes et al. as a significant loss in value (2008, p. 38). Moreover, because high-feature grade held only one third of the value of Medium-feature grade in this study (2008, p. 10) the impact of study design on log residual value would have potentially resulting in a serious underestimate of profitability. The level of this discount was not discussed nor justified and appears to be arbitrary.

These shortcomings illustrate the importance of methods that produce grades that infer end products that can be priced, rather than grading and pricing quality levels in an arbitrary manner. Furthermore, accurate comparison of the three sawmilling methods was not possible because of serious inconsistencies in design and implementation of the experiment.

Innes et al. acknowledged that total product values were not consistent between processing methods being compared (Innes et al., 2008, pp. 19, 28). Although the differences in sawmilling methods were highlighted in this report by comparing recoveries (2008, pp. 18, 28), this result was clearly confounded by significant differences (Innes et al., 2008, p. 8) in grading procedures between the three production techniques used. Other inconsistencies in assessing log values from the three different production methods used by Innes at al. (2008) included:

1. Not specifying green sawn thickness for two of the three sawing methods reported (2008, pp. 4, 6). The third method produced 32 mm green thickness material for a dry skim-dressed board nominal thickness of 25 mm (2008, p. 3). There are clear inconsistencies in sizing that would confound comparisons between recoveries from the different sawing systems.
2. A minimum allowable board length of 1.8 m was reported (2008, p. 9) for Gunns Lindsay Street while a discounted value was allowed for lengths shorter than 1.8 m for ITC Heyfield (2008, p. 28). Furthermore, there was no reject grade for ITC Newood (Innes et al., 2008, pp. 9, 28).

These differences highlight grading methods that varied significantly between treatments. A minimum allowable board length of 1.8 m for one processing method would very likely significantly underestimate comparative profitability and bias the results. Furthermore, the 1.8 m length selected from which to apply discounts was not justified by any market information, nor was the discount level justified.

Another recent Australian study illustrates inconsistencies between reports and between sawing and processing treatments that were applied. Washusen et al.(2008, p. 23) in estimating sawn product recovery from *E. nitens*, reported that boards were skim dressed on the face and back to the nominal size but edges were not dressed. Washusen et al. (2008, p. 24) used the same wholesale prices as Innes et al.(2008) for the three grades used, namely select, standard and high feature grades as specified in Australian standard 2796.1 (Washusen et al., 2008, p. 23). However it was not reported whether grading was undertaken on both faces, or only on the best face. In addition to the grade rules specified in the standard, it was decided arbitrarily that select and standard grades were to also be free of surface checking, sapwood and skip on the skim-dressed surfaces (Washusen et al., 2008, p. 32). Where surface checking or sapwood was present, boards were downgraded from select and standard to high-feature grade (2008, p. 34). Surface checking was recorded as present only if total length of checks on the graded face of the board exceeded 20 mm (2008, p. 44). Furthermore, "a discount of 10 per cent was applied to boards of Select and Standard grades > 1.8 m and < 3.0 m and a discount of 50 per cent was applied to select and standard grade boards < 1.8 m" (Washusen et al., 2008, p. 23). The resulting recovery of select and standard grades was low, as were product values (Washusen et al., 2008, p. 32), resulting in only A$169 average sawn timber revenue per log cubic metre.

There are clear inconsistencies between production, grading and pricing methods used in the available contemporary studies that sought to quantify levels of defect, degrade and product recoveries for *E. nitens* sawn timber in order to estimate log residual value. Grade recoveries combine with prices as sawn timber revenue, a key component of log residual value. Improved methods would be consistent between all variables except the one being tested and would have a logical basis.

In the absence of product sales data for *E. nitens* sawn products, improved estimates of log residual value would consider product prices according to product grades and sizes based on product applications, market demand and market competition. Careful product grading into profiles and pricing of these according to market requirements would provide credibility to an economic analysis of *E. nitens* profitability using the residual value method of pricing logs.

Standardising of grading methods would allow comparisons between studies or treatments to be undertaken by researchers. Standardised methods would also need to be objective in terms of well-defined grade criteria and product profiles that can be priced from market data.

2.2 Sawmill Productivity and Profitability

Sawmill productivity is largely dictated by the suitability of the processing equipment for the logs being sawn. A successful processing operation will cost-effectively utilise as much of the log volume as possible (Nolan et al., 2005, p. 82). Maximising revenue from production of sawn timber requires knowledge of products and pricing of these to target products that produce the highest revenue. However, the full range of products and by-products being produced contribute to overall profitability, including high value products along with lower value products produced at low cost (Nolan et al., 2005, p. 81).

Producing higher grades of timber in lower volumes might be preferable to simply maximizing volume production (Nolan et al., 2005, p. 81). The tradeoff between higher volume production of lower value products and lower volume production of higher quality products at higher cost requires skilled judgment calls by the processor. Good decisions would be based on experience and knowledge gained over time from marketing a range of products and from a good understanding of species log characteristics such as propensity for degrade.

The influence degrade has on product quality and value is largely determined by product application. For example, high-value cabinetry and furniture applications require material free of internal checks, whereas product value for tongue and groove flooring will not be affected by internal checks unless these are exposed on the profiled surface (Blakemore & Northway, 2009, p. 4). Clearly there are many factors that influence target sawn product preference and sawmilling decisions on log utilisation.

For this case study, sawn products selected were assumed to be those most suitable for sawing from the case study logs. Assumptions were required on products that would yield greatest returns from the logs. In consultation with industry expertise these were selected as:

- Solid timber flooring from nominal 100 mm, 125 mm and 150 mm widths; and
- panel-lamination stock from 75 mm and 50 mm widths.

Although there is not an established market for *E. nitens* logs in New Zealand, by estimating sawn timber prices and log revenue, processing costs could be deducted for log residual value. The approach taken in this case study was to employ best practice processing methods identified from the literature, assuming that industry players could reproduce an equivalent productivity on average if they were to utilise these methods. Cost-efficiency improvements would be expected from this benchmark in future as methods improve, with this case study representing average best current practice.

2.3 Log Quality

Log quality is an important factor that determines sawmill profitability. Average log quality needs to be good enough to produce sufficient volumes of higher-grade material for returns to exceed the cost of production (Nolan et al., 2005, p. 83). As log quality increases, production of higher quality appearance grades increases per cubic metre of log processed (Nolan et al., 2005, p. 82). Therefore, sawmills should be prepared to pay more for logs where improved quality is definable and returns justify the higher log price. This is the reasoning behind residual log value. For example, hardness ratings appear to increase with tree age in *E. nitens* (Farrell & Mihalcheon, 2009, p. 11), suggesting that older trees are more suitable for applications such as flooring where surface hardness is desired. If flooring timber were to fetch a price premium in the market, so too could older logs that produce higher quality flooring timber.

Log quality is partly a function of external log quality characteristics such as diameter and form (Alzamora & Apiolaza, 2010). However, other characteristics potentially affecting *E. nitens* log quality may not be visible, such as diameter of knotty core inside pruned logs. Other measurable descriptors that are not visible but may identify quality include tree age, log position and hardness.

Quality characteristics that could potentially influence grade recoveries and therefore log value may not even be detectable in a freshly cross-cut sawlog, such as propensity for end splits, movement, checking and collapse. If such properties were measurable prior to purchase or processing and a relationship could be established between log revenue and these characteristics, log price could potentially be predicted empirically from such characteristics. If log value could be predicted based on quality descriptors, growers could potentially improve their profit by targeting improved log quality.

2.4 Silviculture and Log Value

Market demand for timber products influences prices obtained for the grades supplied. Greatest market demand and value for hardwood timber is as clearwood (Nolan et al., 2005, p. iv). Select grade timber (graded to Australian standards), with its low level of feature, dominates Australia's appearance hardwood market and fetches the highest price premium (Nolan et al., 2005, p. 7). This suggests that growers should target production of clearwood from their trees and logs. Two silvicultural practices facilitate production of clearwood from trees, pruning and thinning.

The purpose of pruning trees is to improve wood quality and thus value of the resulting crop. It is well documented that pruning and thinning of plantation eucalypts is necessary for adequate recoveries of clear appearance grade timber (Shield, 1995, p. 135).

Pruning does not necessarily produce high recoveries of clearwood. Innes et al. reported that “Grade and overall recovery from thinned and pruned butt logs of 26 year old *E. nitens* was no better than from unpruned top logs from the same trees” (2008, p. 19). The logs were described as pruned too late and with a larger knotty core than would be expected from early-pruned stems (Innes et al., 2008, p. 38). In contrast McKenzie et al. (2003, p. 62) reported that the knotty core in *E. nitens* was effectively restricted by pruning in four lifts to 2, 4, 6, and about 8 m at ages 2, 3, 4, and 6 years respectively (2003, p. 65). Recovery of knot-free timber averaged 50% of log volume (McKenzie et al., 2003, p. 72). The implication is that pruning must be practiced properly for high recoveries of clearwood.

As log diameter decreases, the percentage of the log taken up by defect core increases, leading to lower recoveries of higher grades from smaller pruned logs (Washusen et al., 2008, p. 6). Thinning is practiced to reduce crop stocking and increase remaining tree diameters. Washusen et al. (2009, p. 52) found that sawn recoveries as a percentage of volume increased with larger tree diameters and suggested that thinning regimes targeting larger diameters might improve grade recoveries (p. 50).

Silvicultural practices potentially increase sawn timber recoveries and grade recoveries and therefore could improve returns to the grower. Final crop stocking for sawn timber production should be low enough to ensure pruned logs mature into diameters large enough to maximise log residual value. However, to date no attempts have been made to optimise final crop stocking and rotation length for solid timber production from pruned *E. nitens* for specific processing equipment. This study aimed to produce costs and revenues along with graded sawn recoveries for the range of tree diameters present in the case study stand.

2.5 Log Position and Log Value

The literature points to a number of factors that could influence grade recoveries according to log position, suggesting that log position appears to be an important variable for predicting revenue from logs.

With the exception of end-splitting, which was observed to increase in the second log, Washusen et al. reported that upper logs posed fewer processing issues than did buttlogs (2009, p. 52). This implies that upper, unpruned logs might produce profitable sawn grade recoveries. Height in tree was also found to influence both surface and internal checking levels, with less checking occurring at 6 m height than 0.5 m above the ground (Blakemore et al., 2010, p. 32). Collapse has consistently been found to be worse lower in the tree (McKenzie et al., 2003, p. 72; Purnell (1988) as cited in Shelbourne et al., 2002, p. 360). Deflection (movement off the saw), however, was reported by Washusen et al. (2008) to be higher from second logs than from buttlogs (p. 41). Washusen et al. also found that radial shrinkage increased significantly from the first pruned log to the second pruned log (2009, p. 49) and suggested this could result in more skip in boards sawn from the second log.

Because log position appears to be an important variable for predicting revenue from logs, there is a need to examine the effect log position has on recoveries.

2.6 Sawmilling Systems and Factors Influencing Value Recovery

Investigating best practice processing methods that maximise sawn timber and grade recoveries while also minimising production costs would be required to demonstrate economic value from *E. nitens* sawn timber production.

To date, research into production of solid timber from *E, nitens* has primarily examined wood quality issues, processing systems and the relationship between these two. Although a range of studies have quantified sawn recoveries and grade-limiting defects from young, pruned plantation *E. nitens* in both New Zealand and Australia, to date only Innes at al. (2008) published estimates of product value per cubic metre of sawlog and per hectare for plantation *E. nitens* in the public domain.

Innes et al. (2008, p. 1) reported on the profitability of using existing traditional and contemporary Australian native forest eucalypt sawing and drying systems as a first step in exploring utilisation of sawn plantation *E. nitens*. However, Innes et al. identified a range of shortcomings in the production techniques used in their study that resulted in high levels of checking, knots, collapse and distortion (2008, p. 23), thus generating low overall product values (2008, p. 39).

Best practice sawmill methods are those that have been documented to minimise degrade in sawn products. However, there is little published research that reports improvements in economic value from processing *E. nitens* into solid timber products from best practice methods. In order to identify methods most suitable for producing greatest returns from *E. nitens* sawn timber, this section will consider traditional processing methods, then improvements to these before considering contemporary methods.

2.6.1 Traditional processing of ash eucalypt

Cold climate eucalypt species such as the ash group have a set of processing challenges that if not carefully managed result in low grade recoveries, particularly with smaller log diameters such as from the Australian second growth resource.

Conventional single sawing methods, as traditionally practiced on old growth Australian native ash species, can have high processing costs and low nominal sawn recoveries. Washusen (2011, p. 8) attributed these inefficiencies primarily to large saw kerfs, large allowances for green board oversizing and slow throughput because of reciprocating carriages and regular log turning. These inefficiencies are compounded as log diameter and length is reduced (2011, p. 8).

In order to avoid skip and undersizing of products, conventional processors of native forest ash eucalypts in Australia target a mean green board thickness as high as 31 mm to produce dried boards with a nominal thickness of 25 mm (Washusen et al. 2006, cited by Washusen, 2011, p. 8). This oversizing of green board thickness is practiced to eliminate the presence of skip on the faces of boards dressed to nominal sizes, but has the consequence of reducing nominal recoveries as a percentage of the log volume.

Issues with traditional processing are exacerbated with production of appearance timber from plantation *E. nitens*. Washusen et al. (2009, p. 53) practiced conventional ash sawmilling methods on *E. nitens* and attributed high levels of sawn board defects to shortcomings in conventional processing practices, including poor sawing accuracy, inappropriate weighting of drying stacks, lack of control of drying rate in ambient conditions and steam reconditioning applied at sub-optimum moisture contents. Washusen et al. (p. 53) concluded that both sawing and drying strategies needed to be improved for the plantation resource.

2.6.2 Improvements to traditional processing methods

Washusen (2011, pp. 1, 23) suggested that improvements to sawing strategies should include better sawing accuracy and sawmill efficiency, together with "correct oversizing” of green sawn boards. Suggested improvements to drying strategies included better control over moisture gradients in the boards, optimised steam reconditioning and correct weighting of drying stacks (Washusen, 2011, pp. 1, 23).

Innes et al. (2008, p. vi) concluded that for high value sawn products to be produced from *E. nitens* plantations, the sawing equipment would need to be optimised for the plantation resource, with specific processing techniques required to control distortion, collapse and checking. Innes et al. observed that dry recoveries varied considerably between sawmilling technologies (2008, pp. 18, 38) and concluded that for economic production of sawn appearance grade timber from plantation pruned and thinned *E. nitens*, both sawing and drying techniques would need to be improved to provide greater control over distortion and checking (2008, p. 41).

2.6.3 Contemporary sawmill technologies

Washusen suggested that sawmill efficiencies could be improved from traditional methods as practiced on old-growth ash eucalypt by utilising twin and multi saws to symmetrically release stresses on opposite sides of the log or flitch at once (Washusen, 2011, p. 9). Currently available sawmill systems utilising this technology are restricted to small maximum log diameters, including 45 cm for Whittaker’s Timber Products small log line (Washusen, 2011, p. 10), 25cm for the Hewsaw R200 and 34 cm for the Hewsaw R250 (Washusen, 2011, p. 12). However, small sawlog diameter has been identified as a factor that reduces sawn timber and grade recoveries.

In an attempt to improve processing systems for *E. nitens*, Blakemore et al. (2010) applied contemporary sawing, drying and reconditioning schedules to *E. nitens* timber. Boards were sawn on a Hewsaw, a multi-saw linear flow system designed for softwood sawmilling that produces flatsawn boards (Washusen, 2011, p. 16). The Hewsaw removes wood simultaneously from around the log by using chippers ahead of symmetrically oriented multiple circular saws, allowing production of long-length (5 m) flatsawn timber. Sawing longer lengths reduces end splitting as a proportion of green sawn timber (Washusen, 2011, p. 14) and sawing costs are low (Table 1, Washusen, 2011, p. 16), provided an operating log throughput of 120,000 cubic metres per annum is available (Washusen, 2011, p. 12). However, because the sawing pattern cannot be altered for logs of varying diameters, mean green sawn recoveries were reported to be less than 40% for the flatsawing strategy (Blakemore et al., 2010, p. 2), with percentage recoveries reducing as log diameters increased.

Washusen (2011) reported that no attempt was made to evaluate grade recoveries as a percentage of log volumes from two Hewsaw trials sawing *E. nitens*, despite acknowledging that a large proportion of the boards produced would contain pith, which is associated with drying degrade (2011, p. 15). Grade recoveries were not quantified, nor were product values assessed against production costs in these trials.

Issues with the Hewsaw system include limited grade recoveries because of proportionally large defect cores from the small log diameters, the wide flatsawn boards would be subject to cupping and checking defect and because centre boards contain pith, these would be severely devalued for appearance applications. Furthermore, for production efficiency to be optimised the log diameter range is very narrow.

Satchell and Turner reported low levels of defect and high grade recoveries from sawmilling and sizing 18 year old *Eucalyptus regnans*, using a sawmilling method developed for small diameter eucalypt (Satchell & Turner, 2010, p. Results).

The method involved accurate placement of logs for initial saw cuts, skilled judgment calls by the sawyer, predefined log lengths according to diameters, sawing faces before edges and accurate edging for grade recoveries based on visual cues on board faces. The technique involved cutting narrow quartersawn boards in preference to wide flatsawn boards.

Controlling for defect and degrade appears to be essential to achieve adequate grade recoveries from *E. nitens* and study design requires attention to minimising avoidable defect and implementing sawmilling methods that maximise log revenue and minimise costs. By identifying then applying methods that are current best practice, this study approached profitability as a performance benchmark, with cost and grade recovery results that any processor using the case study equipment and methods could expect.

Specific methods applied to sawing eucalypt have been studied and the literature identifies a range of issues with these and how they influence production efficiency and recoveries.

2.7 Factors influencing grade recoveries and sawmill efficiency

To efficiently convert *E. nitens* logs into sawn timber product, the literature draws attention to three main issues: sawing pattern, growth stresses and log end-splitting. Each of these is considered in turn.

2.7.1 Sawing pattern

Sawmill pattern will determine the quantities produced of two distinct types of boards, quartersawn and flatsawn. Strategies tend to target one type of board or the other.

There is widespread disagreement among Australian researchers on the comparative merits of quartersawing versus flatsawing as processing strategies.

In Australia native forest ash eucalypt is generally quartersawn to minimize drying defects and improve the resulting products' stability in service (Blakemore & Northway, 2009, p. 4; Washusen et al., 2008, p. 7). Conventional sawmills prefer log mid-diameters greater than 40 cm for quartersawing (Washusen et al., 2009, p. 41) and "it is well understood that quarter-sawing is a poor sawing strategy for small diameter eucalypts" (Washusen, 2011, p. 6).

McKenzie et al. (2003, p. 71) reported that for a mean log diameter of 480 mm, recovery of quartersawn *E. nitens* timber averaged 50% (2003, p. 72). Although these recoveries are high relative to Australian studies, the methods used for measuring recoveries were poorly reported and it is not clear whether the recoveries were green sawn, nominal or dry, or whether recoveries included end-splits. Straightening cuts were applied in Mckenzie et al. to remove crook when ripping boards from slabs (2003, p. 75). The log length was 5m which required application of regular face cuts to the residual log. Slabs were then reduced to half that length prior to ripping (2003, p. 72). This strategy yielded high sawn recoveries but costs were not reported.

Cost-efficiency is an important consideration when assessing profitability of a sawmilling method because marginal revenue needs to exceed the marginal cost of implementing improvements in recoveries in order to maximise log residual value. Strategies consider the tradeoff between increasing the cost of sawing for higher recoveries and the value of sawn timber recovered.

Flatsawing is a lower cost strategy than quartersawing but the risk is lower grade recoveries. The additional cost of quartersawing may be justified if returns are improved. Although Nolan et al. suggested *E. nitens* should be quartersawn even as small diameter logs (2005, p. 28), there has been a strong preference to flatsaw *E. nitens* among contemporary Australian researchers, primarily because flatsawing produces a consistently higher green-sawn percentage recovery from small diameter logs (Blakemore & Northway, 2009, p. 4). However, producing larger volumes at lower cost may not result in higher revenue. Washusen et al. (2008, p. 2) reported that product values were significantly higher per cubic metre of log sawn using a quartersawing strategy, despite lower volumes produced. This was because a high incidence of surface checking significantly devalued the flatsawn timber.

Another issue influencing sawn timber value is board width. For a given log diameter a flatsawing strategy produces a greater proportion of wider boards (Washusen et al., 2008, p. 7). As log diameter decreases, quartersawing becomes less cost-efficient (Washusen et al., 2008, p. 30), while quartersawn boards also become narrower. Based on the perception that value per cubic metre increases with board width (Washusen et al., 2008, p. 7), Washusen et al. chose a strategy of flatsawing the widest boards possible from pruned plantation *E. nitens* in an attempt to maximize both board width and board grade, therefore value (2008, pp. 2, 17). However, wide flatsawn boards are subject to cupping (Washusen et al., 2008, p. 42), which then results in skip defect. Washusen et al. (2009, p. 53) reported that flatsawn boards from buttlogs had mean cupping of over 2mm. To remove this level of cupping from both the face and back of a board, 5mm of wood would have required to be removed from the thickness (Washusen et al., 2009, p. 53). This would have reduced the product volume significantly and therefore log revenue. It is notable that cupping has less impact on dressed board thickness in both narrower flatsawn boards and quartersawn boards than in wide flatsawn boards.

Tasmanian plantation *E. nitens* timber has approximately twice the amount of tangential shrinkage than radial shrinkage (Innes et al., 2008, p. 41). As a result, flatsawn boards are much more likely to cup during the drying process and move in service when exposed to moisture variation than quartersawn boards (Blakemore & Northway, 2009, p. 4; Kingston and Risdon, as cited in Nolan et al., 2005, p. 28). Washusen et al. (2008, p. 43) found that width shrinkage was significantly lower in quartersawn *E. nitens* boards than in flatsawn boards. This anisotropic shrinkage leads to greater stresses on flatsawn board faces than on quartersawn board faces, resulting in checking and cupping in flatsawn boards (Blakemore & Northway, 2009, p. 4). Furthermore, restraining this cupping potential in the drying stack could lead to an increase in these tension stresses, causing further surface checking (Blakemore & Northway, 2009, p. 4). The implication is that narrow flatsawn boards, with greater freedom to move and lower stresses at work on the board face, might check less during drying than wider flatsawn boards.

Collapse on the face of flatsawn boards is likely to be expressed as checking (Blakemore & Northway, 2009, p. 4). Although collapse can be severe on quartersawn board faces, this is likely to be expressed as washboarding rather than checking (Blakemore & Northway, 2009, p. 4). Checking is a serious value-limiting defect, whereas collapse has no impact on value if removed when profiling the timber.

A range of issues need to be considered in the design of sawmilling methods that minimise degrade, maximise production volumes, minimise costs and produce a quality sawn product. Although quartersawn boards are likely to have lower levels of checking than flatsawn boards and are more stable in service, log diameter affects the cost efficiency and production efficiency with which quartersawn boards can be produced. Study design should use methods that take into account the tradeoff between sawn board quantity and sawn board quality from the log in order to maximise residual value from the sample sawlogs.

Satchell and Turner (2010) evaluated a hybrid pattern (See Appendix C) and reported relatively low costs and high grade recoveries for the scale applicable to this study from small-diameter *E. regnans*. Average small end diameter was 31.8 cm with a diameter range of 25 – 43 cm. This method was selected as the most suitable for sawing the case study *E. nitens* logs because:

- *E. nitens* has a propensity for high levels of surface checking. Quartersawn output was desirable and innovations allowed cost-efficient production of quartersawn output; and
- average log diameters from the case study stand (32.94 cm) were smaller than required for traditional quartersawing patterns (>40 cm).

2.7.2 Growth stresses

The outer section or periphery of a eucalypt log is in longitudinal tension, with a stress distribution progressing to longitudinal compression in the core (A. N. Haslett, 1988, p. 12). Sawing of eucalypt logs and release of stresses results in bent flitches and curvature in the residual log. Regular face cuts may be necessary to produce even thickness flatsawn boards, while edge cuts are necessary to produce straight quartersawn boards. These additional saw cuts result in recovery losses (McKenzie et al., 2003, p. 63) and increased costs.

McKenzie et al. (2003, p. 72) reported that recoveries of quartersawn timber were inversely related to growth stresses in the logs. Larger growth stresses resulted in more distortion of sawn surfaces. Therefore to produce straight boards, straightening cuts removed greater curve from slab edges, consequently reducing sawn timber recoveries.

The radius of curvature (also called ‘deflection’) tends to be greater when sawing smaller diameter logs because stress gradients decrease as diameter increases (Nolan et al., 2005, p. 29; Shield, 1995, p. 134; Washusen et al., 2009, p. 6).

When producing quartersawn material, as log length increases more wood is removed from both edges to straighten the resulting board or cant from ‘spring’ curvature. Sawn recoveries reduce per log cubic metre as log diameter declines, provided log length is constant (Nolan et al., 2005, p. 30). Reducing log length counteracts the effect movement has on recoveries from smaller diameters. However, the consequence is that sawing costs increase because there is more handling for a given volume of logs.

As log length increases, producing even thickness flatsawn material with a single saw requires face cuts of increased thickness on the residual log, flitch or cant to straighten the face. The tradeoff is that production efficiency improves by flatsawing longer logs.

Some contemporary sawing systems such as twin or multiple sawing lines can overcome thickness variation in flatsawn boards by sawing simultaneously on opposite sides of the log (Shield, 1995, p. 136) to symmetrically release stresses on both faces. This allows longer flatsawn lengths to be milled without requiring face cuts, thus improving sawmill efficiency. Crook distortion on edges of quartersawn material is not overcome (Innes et al., 2008, p. 24), because only stress on board faces is relieved by symmetrical cuts. Edge straightening cuts of quartersawn boards over long lengths remain at “the expense of substantial recovery loss” (Blakemore et al., 2010, p. 26).

Washusen et al. (2008, p. 41) reported that slabs quartersawn from the centre to the periphery distorted significantly more than the half log from which the slab was cut. The explanation given by Washusen et al. (2008, p. 41) was that “distortion increases as the sawing process continues”. A more plausible explanation is that half logs do not undergo full stress release between the pith and the periphery perpendicular to the saw cut halving the log. This is because half-log deflection induces counteractive stresses at the peripheries adjacent to the saw cut that were not under tension in the direction of the deflection. This resulting counteractive stress would constrain the full release of tension. Once slabs from this central area are sawn from the residual log they release their tension freely. As the width of a quartersawn slab increases, the stress gradient will be steeper, resulting in increased curvature expressed as crook (Nolan et al., 2005, p. 29). Sawmilling strategies can take advantage of counteractive stresses by releasing these into slabs before applying straightening cuts, thereby increasing production efficiency.

It is important to understand that the radius of deflection is not influenced by log length. However, the level of deflection does increase as the log gets longer. The length tradeoff is therefore between:

- value lost from short logs caused by short board lengths, higher sawing costs and end-splits; and
- value lost from long logs as sawn recovery lost from straightening cuts.

In summary, distortion resulting from stress release does have a negative impact on log residual value. Removing distortion to produce a high quality straightened sawn product reduces sawn percentage recoveries and increases production costs because of the larger number of cuts required. This is a ‘fact of life’ with eucalypt sawmilling and indirectly influences log residual value because there are costs and benefits with different sawmilling approaches.

As log diameter decreases, resulting lower sawn recoveries and higher costs imply an increasingly negative impact on log residual value, compounded by the shorter log lengths required for adequate sawn recoveries.

To ensure sawn recovery remains high as a percentage of the log, log length must be restricted in proportion to the diameter because quartersawn slabs experience edge curvature and with single saws flatsawn slabs experience face curvature. Larger diameter logs, because these move less in proportion to their diameter, can be sawn at longer lengths.

The sawmill method described in Satchell and Turner (2010) produces straightened boards by first sawing slabs and then edging these. Although log length could potentially be optimised according to diameter for greatest residual value, for this case study log length was set to 3.0 m as industry best practice for the diameter range being sawn. Movement off the saw can be easily measured with this sawmill pattern because logs are halved before other saw cuts are made. This offered the opportunity to quantify the effect movement had on sawn recoveries according to log diameter and log position at a standard length of 3.0 m and movement was measured for each sample log.

2.7.3 Log end splitting and log length

Increased levels of log end splitting reduce grade recoveries. Factors influencing levels of end-splits have been reported in the literature.

Sawn timber volume losses from end splitting have been found to be greater in flatsawn boards than in quartersawn boards and to increase progressively with tree height (Washusen et al., 2008, p. 40).

Longer log lengths can reduce volume losses attributable to board end splitting (Blakemore et al., 2010, p. 2). Washusen reported only 1.2 – 2.9% loss in green sawn recovery caused by board end-splits from sawing 5 m log lengths with a Hewsaw (Washusen et al. cited by Washusen, 2011, p. 14).

Satchell and Turner (Satchell & Turner, 2010, p. Results) reported end splitting losses of only 1.4% of nominal sawn recovery, from machine harvested small diameter 6m *E. regnans* logs, cross cut in half to an average log length of 3 m immediately prior to sawing and sawmilled within 28 days of harvesting.

End-splits increase with time after cross cutting of logs. If logs are sawn immediately after cross cutting, end splits are not likely to impact on recoveries to any significant extent, regardless of log length. Therefore best practice is to saw logs as soon as practicable after harvest, to avoid defect resulting from end-splits that would otherwise impact on log residual value.

2.7.4 Knot defect

Although pruning is considered to be essential to overcome defects associated with branches and to produce high value appearance clearwood from plantation buttlogs (Washusen, 2011, p. 3), pruned logs do not necessarily produce high recoveries of clearwood.

Innes et al. (2008, p. 23) reported the presence of knots to be the primary reason for downgrading boards from pruned logs. Inclusion of knotty core in boards from pruned logs can be seen in plates 5-8 (Innes et al., 2008), indicating that edging was not practiced properly to target clearwood from pruned material.

Grade sawing involves a tradeoff between volume production and higher grade recoveries. Sawmilling best practice involves judgment calls aimed at producing grade recoveries that maximise the value of sawn timber produced from the log. Where practicable, sawmilling methods should exclude knotty core from boards. This can be achieved by visually assessing where slabs are to be edged and taking care to edge out knotty core for production of clearwood.

Edging of unpruned logs also requires similar judgment calls to target higher grades by excluding corewood and where practicable excluding knot defect.

Sometimes knot defect can be excluded by edging and other times this is best docked out from the board length. Knot defect inevitably reduces grade recoveries from headlogs, however the impact knots and pruning have on *E. nitens* log value is not well understood. By examining relationships between levels of knot defect in boards and log attributes such as log position and log diameter, improved forest management practices could result that lead to higher log prices for the grower.

2.7.5 Summary and proposed methods

A range of methods are available to the sawmiller that can potentially reduce defect in the resulting sawn timber. Sawmilling pattern can affect volume recovery, costs and grade outcomes along with levels of checking that develop during drying. Growth stresses and end splits can reduce sawn timber recoveries and increase costs for producing these. Shorter log lengths reduce recovery losses caused by growth stress, but at the expense of increased sawing costs. End splits are unavoidable but defect resulting from these can be minimised by sawmilling soon after cross cutting logs.

This study aimed to use best practice methods identified in the literature for converting case study logs into sawn timber, in order to maximise log residual value and therefore returns to the grower. Sawmilling method as practiced in Satchell and Turner (2010) was selected, with 3 m long lengths sawn soon after cross cutting to length to minimise defect from end splits.

This study also aimed to quantify knot defect present in boards from pruned buttlogs and unpruned headlogs, along with recoveries of sawn timber to examine the effect knots have on grade recoveries and log residual value.

2.8 Drying Degrade and Log Value

In order to produce high-quality appearance hardwood products from plantation *E. nitens* logs, significant levels of defect must not develop in the drying process (Washusen, 2011, p. 18). To avoid levels of drying degrade that impact seriously on economic value of sawn products, *E. nitens* timber must be dried slowly and with care (Nolan et al., 2005, p. 31), particularly in the early stages (Nolan et al., 2005, p. 32).

Washusen rated checking as the drying defect having the greatest impact on product quality (2011, p. 19). Blakemore and Northway (2009, p. 45) identified checking as "the major limitation for processing pruned plantation grown *E. nitens* into appearance grade products".

2.8.1 Drivers of checking degrade

Initial drying that takes place too rapidly has been associated with increased internal checking and collapse in *E. nitens* (Nolan et al., 2005, p. 31).

Normal shrinkage (i.e. shrinkage not associated with collapse) across a tangential board face can cause high levels of stress to develop, leading to surface checking (Washusen, 2011, p. 19). Jacobs (as cited in McKenzie et al., 2003, p. 63) reported that collapse in the flatsawn face of a board can "show as heavy open checks with distortion of the surface as well".

Collapse shrinkage, unlike normal shrinkage that occurs below fibre saturation point, is also implicated in much of the surface and internal checking experienced in low to medium density eucalypt species (Blakemore & Northway, 2009, p. 9; McKenzie et al., 2003, p. 63; Washusen, 2011, p. 19).

Shelbourne et al. (2002, p. 378) reported that checking in kiln dried *E. nitens* disks was representative of checking in sawn boards and found that:

- Checking levels appear to be variable more at the individual tree level than provenance or site, with a large range of checking levels evident between trees (2002, p. 373);
- checking levels decrease with tree height (2002, p. 378); and
- checking was more frequent in the transition wood zone (2002, p. 371).

Internal checking in *E. nitens* may not be related to tree age, with high levels of checking reported by Yang and Waugh (as cited in Shelbourne et al., 2002, p. 360) in 15, 25 and 29 year old trees.

Levels of internal checking in dry *E. nitens* boards increase with board thickness (Blakemore et al., 2010, p. 18). Blakemore et al. (as cited in Washusen, 2011, p. 22) reported that thin section quartersawn *E. nitens* could be processed to be virtually free of surface and internal checking. As board thickness decreases, earlywood collapse may express as washboarding rather than internal checking (Blakemore & Northway, 2009, p. 4).

Washusen et al., using conventional native forest ash eucalypt processing strategies, found the incidence of surface checking to be high (2008, p. 45). Haslett & Young reported high levels of checking in quartersawn boards from 30 year old *E. nitens* timber kiln-dried after what they described as "careful air drying" (T. Haslett & Young, 1992, p. 8). However, Haslett and Young (1992, p. 9) reported that twisting of boards during drying was also a serious problem, suggesting that drying was not practiced carefully. This is because twisting is preventable and well known to be caused by either not weighting the stack properly or drying the wood too fast. Because no detailed description of the drying process was outlined in the report, neither the timber nor the level of care can be clearly implicated as causing these poor results.

Innes et al. proposed further research to address the drying of *E. nitens* (2008, p. vii) because using current Australian industry drying methods, 15-40% of boards from pruned and thinned *E. nitens* buttlogs contained significant levels of internal checking (2008, p. 40). However, review of subsequent literature has not revealed any clear understanding of drivers that cause checking, nor methods to prevent the problem. Indications from the literature are that to limit checking to levels that do not impact heavily on economic value, current best practice includes:

- Slow drying of timber, especially during the early stages of drying;
- quartersawing where practicable; and
- limiting board and product thickness.

This study did not seek to develop specific methods for reducing checking, nor to quantify impact on economic value of tree age or variation between individual trees for the species. The intention was to undertake best practice methods identified in the literature, then assess their influence on case study log and stand residual value.

This study practiced methods that were intended to minimise levels of checking given what is currently understood of the issue. Product thickness was sawn to 28 mm and timber was slow air-dried.

2.8.2 Log position and checking

Checking of sawn timber from *E. nitens* buttlogs has been reported as the most serious value-limiting defect in several studies (Innes et al., 2008; McKenzie et al., 2003, p. 76; Washusen, 2011; Washusen et al., 2008, 2009). Innes et al. (2008, p. 23) reported that levels of checking were higher in pruned buttlogs (the primary reason for downgrade in 25-30% of boards) compared with unpruned upper logs (the primary reason for downgrade in 8-10% of boards) from the same trees. Blakemore et al. (2010, pp. 3, 31) reported that levels of both surface and internal checking decreased with height in the sawlog and also found that unpruned buttlogs yielded greater levels of internal checking than pruned buttlogs, especially before reconditioning. Washusen et al. (2008, p. 2) found that upper pruned logs produced significantly higher product values per cubic metre of log input than lower pruned logs, primarily because of reduced surface checking.

The importance of log position has been clearly identified in the literature as influencing levels of checking. This study aimed to quantify levels of checking according to log position to examine the impact log position has on log residual value.

2.8.3 Steam reconditioning and checking

Traditional processing of Australian native forest eucalypt involves steam reconditioning once the moisture level within the boards reaches fibre saturation point (Washusen et al., 2008, p. 20). Contemporary reconditioning strategies have been developed in Australia where greater collapse recovery is achieved by reconditioning at lower moisture contents than traditionally used (Blakemore & Langrish, 2007).

Blakemore et al. (2010, pp. 31, 42) reported that the prevalence of visible internal checking was dramatically reduced from that reported previously by reconditioning only once board moisture content was below 20% (2008, p. 18) or fibre saturation point (2008, p. 20). However, closed checks (i.e. those that were not visible) were not reported (Blakemore et al., 2010).

Checks can be ‘closed’ by steam reconditioning, which makes them less visible (Blakemore et al., 2010, p. 2). However, although the visibility of checks can be significantly reduced (Blakemore et al., 2010, pp. 41, 42), “The impacts of closed checks in reconditioned sawn boards from plantation-grown *E. nitens* in a range of downstream manufacturing processes and in product service needs to be determined.” (Blakemore et al., 2010, p. 3). Closed checks on the surface of a board are visible in finished products and “the closed-up hairline cracks remain” (Blakemore et al., 2010, p. 44). These could open up later in service or ‘feather’ during secondary processing, resulting in defective product (Blakemore & Northway, 2009, p. i). The impact closed surface checks could have on appearance product values has not yet been studied, but closed surface checks could potentially be a worse problem than open surface checks which are clearly visible and result in downgrading of the material (Blakemore & Northway, 2009, p. i). Washusen (2011, p. 1) identified this issue as an important knowledge gap in need of further research. Blakemore and Northway (2009, p. 16) described it as follows:

> Conventional industry wisdom is that such closed checks pose a serious problem, in that if exposed when machining or moulding is undertaken, they will result in a feathering effect on the surface of the product. This may not be a significant problem for products such as quartersawn flooring, but it is a problem for backsawn products and cabinetry components such as high-value kitchen cupboard doors.

It can be concluded that reconditioning does not actually remove checking degrade but does confound attempts to measure levels of checking in research experiments. A standardised approach to quantifying levels of checking would allow future research to potentially compare conflicting results and isolate the causes of checking.

Direct comparisons of checking degrade between processing studies would require either an identical reconditioning process or none at all. By describing closed checks as “not visible” (Blakemore & Northway, 2009, p. 16), this implies that closed checks may not be visible to graders or researchers. Thus true levels of checking degrade resulting from the processing treatment being tested would not be measurable. In contrast, by not steam reconditioning timber, levels of degrade caused by surface checking such as length and width of checks or their prevalence could be accurately measured and quantified. However, assumptions would need to be made on levels of skip caused by collapse.

2.8.4 Collapse degrade and steam reconditioning

Collapse shrinkage, unlike normal shrinkage that occurs below fibre saturation point, is considered to be severe ‘abnormal shrinkage’ because it occurs in timber above fibre saturation point (Blakemore & Northway, 2009, p. 9).

Collapse shrinkage of *E. nitens* can be recovered by steam reconditioning. Up to 95% of collapse shrinkage in air-dried boards can be recovered (Blakemore & Northway, 2009, p. 13), effectively reducing the levels of shrinkage in the board. This allows green sawn sizing to be reduced without an increase in skip defect, resulting in increased nominal sawn recoveries. The extent to which boards should be oversized in the sawing process would thus be dependent on whether the boards were to be steam reconditioned. The cost of steam reconditioning should be economically justifiable by the improved nominal recovery and value that results from reduced green sizing.

The case study timber was not steam reconditioned. This allowed for accurate measurement of levels of checks on profiled surfaces. Although the green thickness of 28 mm was selected as industry best practice for eucalypt species in New Zealand, the optimum thickness for highest residual value for unreconditioned *E. nitens* was unknown. Therefore a scenario was designed to enable an economic comparison to be made between residual value for unreconditioned and reconditioned timber, assuming that all collapse would have been recovered sufficiently if reconditioned to have been profiled without exhibiting skip.

This approach also allowed for an evaluation of skip defect on the profiled case study boards given the chosen green thickness, while also allowing for the importance of steam reconditioning to be quantified in economic terms.

2.8.5 Summary and approach to drying

In conclusion the literature is not currently clear about the degree to which levels of checking can be predicted or explained in sawn *E. nitens* timber. This study aimed to develop and document methods for measuring checks suitable for standardising and applying to future research, to facilitate improved research methods examining causes of checking. To date methods for defining or measuring checks have not be standardised.

Methods selected as best practice to minimise levels of checking were to saw the timber to 28 mm green thickness and air dry the timber as slowly as practicable.

This study aimed to:

- Apply best practice drying methods to reduce levels of checking as much as practicable;
- quantify levels of checks on unreconditioned profiled surfaces and examine their impact on sawn timber value; and
- assess the economic impact of steam reconditioning on log residual value.

2.9 Air Drying of *E. nitens*

Two drying methods are applied to drying appearance hardwood timber. These are:

- Air drying followed by kiln drying; or
- kiln drying from green.

Air-drying is the predominant method used in Australia for drying eucalypt species that are known to require slow drying (T. Innes, pers. comm.).

McKimm et al. (as cited in Shelbourne et al., 2002, p. 360) found air drying of 20 year old *E. nitens* followed by kiln drying resulted in less internal checking than kiln drying from green.

The largest sawmill in Australia processing ash eucalypt (Heyfield, Victoria) exclusively uses air-drying and wraps stacks with permeable cloth in warmer periods of the year (T. Innes, pers. comm.). Air flow, temperature and humidity all influence the rate of drying and during drier, warmer periods of the year wrapping freshly sawn timber stacks slows the rate of drying and avoids excessive degrade (T. Innes, pers. comm.). Air-drying appeals to producers because it is low cost and does not require energy nor high capital input (T. Innes, pers. comm.). Priest et al. (as cited in Bekele, 1995, p. 5) reported that 25 mm thick *Eucalyptus grandis* air dried with less degrade than kiln dried material and produced a more uniformly dry material when finished in a kiln than material dried from green in a kiln. Gough (as cited in Bekele, 1995, p. 5) also found that best results were obtained from finishing air-dried *Eucalyptus* timber in a solar kiln. In contrast Washusen et al. (2000, p. 7) reported that slow air-drying of 40 mm thick *E. globulus* produced high levels of degrade similar to *E. globulus* that was slow kiln-dried from green. McKimm et al. (as cited in Shelbourne et al., 2002, p. 360) found air drying of 20 year old *E. nitens* followed by kiln drying resulted in less internal checking than kiln drying from green.

The literature points to conflicting results in the few reports available that compare the two standard methods for drying eucalyptus timber. It was decided that the risk was too high to dry the case study timber from green in a kiln and to use Australian industry standard practice methods for ash eucalypt and slow air dry the timber, followed by finishing in a kiln.

The three elements that control drying rate are air temperature, relative humidity and airflow across the timber surfaces (Langrish & Walker, 2006, p. 1). Unlike temperature and humidity, controlling air flow can be achieved at low cost, such as by wrapping with permeable cloth.

Two methods were available for air drying the case study timber, either drying in a protected environment such as a ventilated shed, or drying outdoors. No literature was available suggesting which would produce the better grade recoveries or pointing to which method would produce higher log residual value. It was assumed that wrapping of stacks would benefit the drying process and it was decided that both air-drying methods should be tested in order to compare resulting sawn timber value.

2.10 Price of sawn timber and residual value

Price is one of the main determinants of profitability in an investment analysis. Because *Eucalyptus nitens* is not sawn commercially in New Zealand, market transaction data for sawn timber is not currently available for estimating log value.

Satchell and Turner (2010) used the residual value method for estimating log values for 18 year old *E. regnans* in New Zealand from sawn timber products, because there was not an established market in New Zealand for sawlogs. Board prices were estimated from those for more commonly available eucalypt species.

In Australia, Innes et al. (2008) utilised the residual value method for estimating *E. nitens* plantation profitability using native forest eucalypt sawing and drying systems. More recently Forestry Tasmania produced a commercial in confidence report on profitability of plantation *E. nitens* using the residual value approach to value sawlogs (Pearn et al., 2013). Price data for similar available species were used for the appraisals in these studies because *E. nitens* timber was not yet available on the market in Australia from which to derive prices.

E. nitens is not a recognised hardwood species in New Zealand timber markets. Consequently, market prices for products are not available. Issues and opportunities for pricing *E. nitens* sawn products are outlined below.

2.10.1 Pricing *E. nitens* sawn timber products

Hardwood solid timber product values have traditionally been linked to grade, board thickness, width and length (Nolan et al., 2005, p. 7). Innes et al. used product prices for native regrowth ash eucalypt in assessing the economic viability of processing plantation *E. nitens*, with high arbitrary discounts applied to lengths shorter than 1.8m when pricing *E. nitens* timber (2008, pp. iv, 9, 10). Another published Australian study on economic viability of *E. nitens* solid timber products discounted board lengths of less than 3m by 10% while boards of less than 1.8 m were discounted 50% from current hardwood wholesale prices (Washusen, 2011, p. 14). No basis for these discounts were provided in the reports and no evidence is available to suggest that the market discounts lengths less than 1.8 m to these levels. Sawn appearance timber is usually available in New Zealand in random lengths, meaning that short lengths are mixed with longer lengths in the packet of timber. Although this suggests that average piece length may be more important to customers than discounts for shorter lengths, the level to which length influences price for appearance timber products is not evident in the literature, nor in the market. Arbitrary discounts do not adequately reflect true market value for the levels of the quality being discounted, suggesting that empirical methods in use for pricing of quality characteristics in products new to market could be adopted as an improved method for pricing *E. nitens* timber.

In an attempt to produce credible estimates of market prices for the range of products sawn, market survey methods were developed by Satchell (2015) to estimate market prices for *E. nitens* sawn products in the absence of market sales data. These methods were designed to overcome some of the inadequacies of previous work examining profitability of growing *E. nitens*.

2.10.2 Market recognition

Plantation *E. nitens* timber is not currently available, nor marketed in New Zealand. Plantation ash eucalypt is available inconsistently and only in small quantities. A recent survey of specialty timber merchants and users by Future Forests Research (unpublished, 2012) described market recognition and availability of plantation ash eucalypt in New Zealand as negligible.

A well known and established species in the marketplace tends to hold consumer preference. This preference generates price premiums and is based on the perception of suitability for purpose (Nolan et al., 2005, p. 8). Established products and species can be resilient and hold strong loyalties, while new products may be accepted only slowly (Nolan et al., 2005, p. 80). For example, hardwood has traditionally been available in long clear lengths but these are likely to become increasingly difficult to obtain into the future (Innes et al., 2008, p. iv). Substitution of long lengths for shorter lengths might meet market resistance because of the perception that installation costs increase. Market penetration and product acceptance could be slow, even if end matching of short floorboard lengths offered low installation costs. Intangible qualities such as reputation could potentially be estimated as price discounts or premiums. Satchell (2015) surveyed flooring timber experts in New Zealand and asked them to quantify the influence on price of four intangible qualities of flooring timber.

2.10.3 Product substitution and price

High quality logs of extant old-growth hardwood timber species are expected to become increasingly scarce into the future (Sandy Chen & Matt Wood, 2011, p. i). Although opportunities might arise for product substitution based on demand for old growth timber not being fully supplied, estimating such demand over time would remain speculative.

Market acceptance, demand and price of a product new to market might best be predicted by comparing quality with established products and soliciting market feedback on suitability for purpose.

2.10.4 Product differentiation

Products with quality differentiation tend to hold higher value in the market along with less price volatility than commodity products (Nolan et al., 2005, p. 80). Seasoned appearance hardwood products are differentiated and include those used for decorative structural applications (Nolan et al., 2005, p. 5).

Both physical and appearance characteristics determine whether a species or product is suitable for a differentiated end-use. Matching wood quality characteristics with technical requirements for specific timber products would be necessary to offer quality differentiated *E. nitens* products (Nolan et al., 2005, p. 91). Physical properties such as movement in service for appearance products, surface hardness for flooring products and strength/stiffness for structural products, could each influence market price of *E. nitens* timber for the differentiated application. These quality characteristics could also be compared between species when pricing a product new to market.

2.10.5 Species comparisons

Innes et al. used product values derived from native regrowth ash eucalypt for valuing plantation *E. nitens* timber and considered plantation *E. nitens* to have the potential to meet market requirements currently satisfied by Australian native forest ash eucalypt (Innes et al., 2008, p. iv). Washusen et al. also considered plantation *E.*

nitens timber suitable for meeting market requirements currently satisfied by Australian native forest ash eucalypt (2008, p. 4). However, Blakemore et al. considered the appearance of plantation *E. nitens* timber to vary from Australian native forest ash eucalypt because of wider annual growth rings (2010, p. 44). Differences in appearance if quantified as a comparative premium or discount might provide some credibility to an estimate of price for a new species if empirical methods were employed. Assessing the effect appearance has on price could involve market feedback mechanisms: The value individuals place on appearance could be compared between two species, revealing preference and willingness to pay for the species being compared.

Beadle et al. suggested that quality and performance of a product new to market would need to meet or exceed those for the species being substituted (Beadle et al., 2008, p. 53). It might be more plausible however, to assume that levels of a quality, if lower in a substitute product, would not meet outright market rejection but instead be discounted. Surface hardness for Tasmanian plantation *E. nitens*, at around 4.5 to 5.3 kN (Janka hardness), was considered by Blakemore et al. to be marginal for flooring applications (2010, p. 44). Consumer preference for a harder species only means the consumer is willing to pay less for the softer species.

Price premiums or discounts could be measured for different levels of quality characteristics. Price adjustments from the product being substituted could represent the different levels in the new product being priced.

Comparisons were used by Satchell (2015) to produce price estimates for *E. nitens* as a timber species new to the market. Comparisons were made by survey respondents for different levels of quality characteristics between species. Price discounts and premiums were determined for 15 year old *E. nitens* compared with

Victorian ash based on appearance, hardness and movement in service levels. (Satchell, 2015).

2.10.6 Product profiles

Both grade and size of hardwood appearance sawn products influence their value to the consumer (Nolan et al., 2005, p. 7). Nolan et al. measured unweighted average market prices of wholesale eucalypt hardwood flooring product profiles, with prices measured relative to a benchmark grade, width and thickness (2005, p. 7). Prices were found to increase with higher grades (i.e. less feature) along with thicker and wider boards (Nolan et al., 2005, p. 7). Nolan et al. also stated that longer boards attract a price premium over shorter boards (2005, p. 7) but did not quantify this.

For results of an investment analysis to be credible where the products are not yet available and sold in the market, methods should attempt to accurately estimate what buyers in the market would be willing to pay for each product based on grade, width and length levels.

Quantifying sawn timber revenue from a log requires prices for the full range of profiles produced. In response to the need for market prices for *E. nitens* timber to establish log residual values, Satchell (2015) reported price estimates as discounts and premiums for levels of width, length and grade quality characteristics for *E. nitens* flooring timber.

Satchell (2015) performed a market survey to elicit respondents' judgements of price for the *E. nitens* flooring product profiles. These were represented as discounts and premiums for the levels of quality characteristics produced in this case study.

Two value-based social survey methods were employed by Satchell (2015) to price the *E. nitens* flooring product profiles produced in this case study:

1. Dollar metric pricing of utility and part worth utilities using the graded-pairs comparison approach.
2. Constant-sum allocation pricing of part-worth utilities.

Both methods are self-explicated stated preference approaches that directly estimate utilities for each product profile.

Satchell (2015) quantified discounts and premiums for the different levels of quality characteristics that made up each product profile.

Results were a monetised numeric estimation of maximum acceptable price to the consumer relative to the given price of a reference product (Monroe, 1990, p. 122). Rather than assuming that *E. nitens* and Australian ash eucalypt hold equivalent economic value, by taking differences in appearance, hardness and movement in service into account, price for *E. nitens* substitute products were estimated without market prices being available. By directly comparing quality attributes, including appearance, Satchell (2015) prompted survey respondents to use normal consumer behaviour in comparing price and levels of attributes between species and products in deciding a maximum acceptable price they would be willing to pay for each *E. nitens* product.

This case study utilised Satchell's survey discounts and premiums (2015) for quality levels to price the *E. nitens* sawn flooring products in order to estimate log revenue for both survey pricing methods.

2.10.7 Residual value approach for pricing products

The residual value method can be applied to infer price for a product used to manufacture other products (Kengen, 1997, p. 44). Such indirect pricing offers an alternative to arbitrary discounts for quality characteristics not readily priced in the market such as board length. For example, short floorboard lengths could be priced by estimating the value of a finished floor laid from short lengths, from which installation costs would be deducted to result in the price for the raw product. By comparing with a floor laid from long lengths and with a known price, a discount for the new product could be estimated.

Glue-lamination and finger-jointing of short length appearance hardwood may offer opportunities for product innovations such as pre-finished laminated parquet flooring and laminated panels (Shield, 1995, p. 137). Where price for an innovative manufactured product is not yet available from sales data because it is has not achieved market penetration, market surveys offer an option for empirically estimating product prices. By deducting costs for a residual value, products such as timber ‘shorts’ that are traditionally perceived to be of low value, could then potentially be priced from the manufactured product.

This study estimated some product values by taking into account innovations and changes underway in the market because of the long time frames involved with growing trees and because products and prices establish log residual values.

Product residual value was selected for pricing short floorboard lengths. Satchell (2015) priced short lengths of solid flooring *E. nitens* from their appearance as a finished floor by comparing the appearance with a floor made from longer lengths and asking survey respondents to judge utility. Costs of producing and installing end-jointed and end-matched product were estimated and subtracted for residual product values for two levels of short lengths.

Product residual value was selected for pricing case study boards of widths too narrow for standard flooring but suitable for laminating into panels (75 mm and 50 mm widths). Sample panels were produced and sold and production costs were quantified.

2.11 Conclusions

The literature reviewed in this chapter indicates that any study that seeks to estimate profitability of growing *E. nitens* for solid timber products needs to consider a wide number of factors. While the concept of residual value is straightforward, its application to the process of sawing and producing timber products necessitates the consideration of many factors, including the application of best practice sawmilling and drying methods for converting logs into sawn timber products.

Important components identified in the literature review relating to residual value include: Processing costs, grade recoveries and defect levels, log diameter, log position, checking, collapse, end-splits and movement. The literature also shows factors that have the potential to improve residual value and profitability such as application of best-practice silvicultural methods, best-practice sawmill and drying methods and selection of highest-value products to saw. These factors and their influence on residual value will inevitably change as improvements are made over time.

The general research objective of this study is to estimate the profitability of growing *E. nitens* for solid timber products as a case study. The case study was a small woodlot of well managed *E. nitens*, grown for 15 years, pruned to 6.5 m and thinned for solid timber production. To achieve this general objective, methods were also developed that could be applied consistently in future studies assessing log residual value for *E. nitens*.

Taking into account the findings of the literature review suggests the following specific research questions:

1. What is the estimated residual value and resulting net present value for *E. nitens* in this case study?
2. What is the impact of degrade and defect on sawn timber value?
3. Is it likely to be profitable to grow *E. nitens* under the case study scenario?
4. What effect does drying method have on wood product quality and value?
5. Does log position in the tree affect wood product quality, and if so, case study log residual value?
6. Does log diameter affect processing costs and sawn timber value, and if so, case study log residual value?

A design to address these research questions was developed and the key features of the design are:

- To apply sawmilling method as practiced in Satchell and Turner (2010) , with 3 m long lengths sawn soon after cross cutting to length to minimise defect from end splits and sawn to 28 mm thickness;
- to apply best practice drying methods to reduce levels of checking as much as practicable;
- to quantify levels of checks on unreconditioned profiled surfaces and examine their impact on sawn timber value;

- to assess the economic impact of steam reconditioning on log residual value.
- to trial two methods of air drying that offer different costs to compare the outcomes in economic terms. The study compared air drying outdoors with the more expensive option of air drying indoors in a ventilated drying shed;
- selection of products to saw that represented the least risk and greatest value. Solid timber strip flooring was selected as the target product for processing from case study logs for the purpose of determining log residual value. This was assumed to be the most marketable and least risky product to produce and price. The market for solid strip flooring is negligible for flooring board widths under 100 mm, so the product selected for 75 mm and 50 mm board widths was laminated appearance panels;
- selection of methods for pricing final products that represented how the market would value these. Prices for products produced in this research were identified as an important component that determines economic viability of growing *E. nitens* for sawn timber. Methods for pricing product profiles as accurately as possible were identified and selected for estimating prices for sawn products. These were discounts and premiums according to product profiles for both the graded pairs and constant sum allocation methods reported by Satchell (2015), modified for short timber lengths as residual product values in the graded-pairs method. Panel laminating stock was priced according to residual product values.

The next chapter considers in detail how this study design was put into practice.

Chapter 3
Methods

3.1 Introduction

Methods for processing logs into sawn product were required that minimised degrade, minimised costs and maximised grade recoveries to represent current industry best practice in converting *E. nitens* logs into profiled timber products. Prices for grade profiles were required in order to estimate sawn timber revenue for each sample log, as were detailed costs for each production process.

The methods chapter is divided into:

1. Methods to estimate sawlog volumes from the case study stand in order to estimate per-hectare volumes according to log categories, including sawlogs as diameters and according to log position, along with volumes of pulpwood/firewood logs.
2. Methods for processing logs and estimating production costs.
3. Methods for quantifying and categorising sawn timber grade recoveries and defect.
4. Methods of assessing and analysing log physical properties.
5. Methods for assessing costs for growing, harvesting and processing of logs.
6. Testing two drying methods and comparing the results between these.
7. Methods for estimating sawn timber revenues.
8. Methods for calculating residual log value and cash flows for the case study.
9. Scope and limitations for the case study.

3.2 Case Study Trees

The case study comprised a small stand of 55 *E. nitens* trees in two distinct but immediately adjacent areas, that were planted by farm forester Patrick Milne near Rangiora on a reasonably well drained but moist fertile Canterbury plains site exposed to the west. These trees were planted at 3 m x 3 m spacing and were pruned and thinned in expectation of solid timber production. The trees were 15 years old at harvest. All trees in the case study stand were measured for diameter at breast height (DBH) and height. Height measurements were recorded with a vertex III hypsometer. The exact position of each tree in the stand was mapped (see Appendix B).

3.2.1 Inventory and plots

Because the case study stand was not a contiguous area of trees, two plots, each 28 m x 8 m, were placed on the scale diagram to avoid edge trees and to provide plots that held representative stockings for a larger hypothetical stand (Appendix B). An inventory of tree heights and tree diameters at breast height over bark (DBHOB) was produced from these two plots. Values for the two plots were averaged.

A Volume and Taper Equation for New Zealand Grown *Eucalyptus nitens* (Gordon, Hay, & Milne, 1990) provided volume and taper equations used for estimating plot log volumes, stem volumes and estimates of log SEDs. Log volumes and diameters were estimated from 0.3 m upward based on 3 m log lengths.

Logs were allocated to categories according to small-end diameter under bark (SEDUB):

- Waste = 0-10cm;
- pulp logs = 10-25cm; and
- sawlogs > 25cm.

Logs 1 and 2 from every tree were also classified as 'pruned buttlog'. Logs above 3 were classed as 'unpruned headlog'.

Average plot tree numbers were scaled to a per hectare value, along with basal area, stem volumes, average diameters (DBHOB).

3.2.2 Case study logs

Trees harvested for sawmilling were selected to avoid edge trees and to represent the range of diameters present inside the stand. The other selection criteria requested by the owner was to production thin in order to evenly open up the stand and encourage further growth in remaining trees. This did not involve any specific selection criteria except that trees were harvested from throughout the stand and represented the full range of diameters. Trees were harvested manually using a chainsaw and logs were immediately cross cut to 3 m lengths. Tree and log position numbers were marked on the logs and these were loaded onto a self-loading truck. Each of three log loads were weighed at a weighbridge and gross weight recorded. The empty truck was also weighed and total log weight calculated. Log specifications were to cross cut to a small end diameter of 25cm, however these were in most cases cut to 30 cm. Trees were reported as pruned to approximately 6.5 m, therefore the first two logs were classified as pruned buttlogs and above log two were classified as unpruned headlogs. No more than five logs were extracted from any one tree. Eight trees were harvested from which thirty-two sample logs were milled.

Each log was painted on both ends with a base colour to represent the tree. Log positions were represented with a matrix of dots painted over the base colour with different colours representing each log position.

Logs were not debarked prior to sawmilling. The ends of each log were measured soon after cross cutting. Due to the oval nature of many of the logs, diameter was measured twice at each end from two perpendicular positions. These two measurements were averaged to produce an estimate for each end diameter. The log volume was then estimated using Smalian's formula.

Individual sample log volumes were summed for a total sample log volume.

3.2.3 Volumes and weights

Tare was deducted from gross weight of each truckload and net weights were summed for total weight of sawlogs.

Total volume for logs was calculated by summing the volume of each log. Average green density per log cubic metre was calculated by dividing total weight for the logs by their total volume.

Slabwood was reloaded on the truck after sawmilling was completed and this was weighed four days after completion of sawmilling.

Board green weight was calculated by multiplying board green volume by weight per cubic metre.

Sawdust weight was assumed to be the difference between total weight and board weight plus slabwood weight.

3.3 Sawmilling

All logs were milled within five days of harvesting. This time frame was considered to be adequate to minimise defect in boards caused by end splits, but realistic for operational implementation. Although end-splits became evident on log ends over this time these were not severe in any logs.

Sawmilling took place on 29 November 2012 to 2 December 2012.

All logs were milled using exactly the same pattern (see Appendix C). Slabbing was undertaken with a Woodmizer LT 40 horizontal bandsaw with a 3mm kerf. Logs were first cut through the pith after raising the log small end so the pith was parallel with the bed. Where necessary, measurements were taken from the bed to ensure the pith was level before making the first cut. Immediately after the first cut was made, measurements of deflection were taken at each end of the log and averaged. The log was kept intact and the two halves together turned 90 degrees. Again the small end was raised so the pith was level with the bed. The log was then slabbed at 28 mm thickness with each pair of slabs removed from the log on the return of the saw head. These dropped directly onto rollers that stockpiled slabs beside the Woodmizer twin-blade edger. Once approximately half of the log was removed as slabs, the two remaining cants were rotated 180 degrees and slabbed to the bed.

The Woodmizer twin blade edger operated simultaneously with the bandsaw for an efficient workflow so that as slabs were fed to the edger from the bandsaw these were edged. A separate operator ran the edger who both edged slabs and fillet stacked edged boards. Fillets were dry *E. nitens* with a thickness of 19mm and width of 25mm. Seven fillets were placed at 0.5m distances apart over each layer of boards and directly above the previous row of fillets, including at both ends of the stack. For each log, the time it took to slab, from loading the log on to the bed to the completion of slabbing, was measured in minutes. The stockpile of slabs waiting to be edged was observed to not increase during the slabbing process for each log and thus it was decided that recording the time the second operator was edging and stacking was not necessary, this being equal to the time recorded for slabbing.

Boards were edged to the following green widths:

- 150 mm nominal = 165 mm green
- 125 mm nominal = 133 mm green
- 100 mm nominal = 108 mm green
- 75 mm nominal = 82.5 mm green
- 50 mm nominal = 57 mm green

Units of electricity and fuel were recorded per hour of operation along with prices for these (see Appendix A5).

Edging was based on judgement calls aimed at optimising value in preference to volume. This ‘grade sawing’ was undertaken by eye with no laser guidance. Slabs were first flipped and degrade was visually assessed on both faces prior to a decision on target board width and where to edge the slab for maximum value recovery. The pith was always removed and judgement calls were made on how much of the knotty core would be removed. The edge closest to the periphery was usually removed as close to the periphery as possible. The Woodmizer twin-blade edger uses rollers to feed the slab through two circular saw blades, producing straight parallel edges at the width set by the operator. The slab is presented to the rollers freestyle with no fence for guidance.

The corewood was observed to have a contrasting colour to the surrounding sound wood when freshly sawn and was only present adjacent to the pith in quartersawn slabs containing central wood. In pruned logs this was always contained inside the pruning wounds. Unpruned logs had a corewood zone of similar size, but with knots extended outside of this. Where possible, corewood adjacent to the pith was edged out from slabs, regardless of whether the corewood was from pruned or unpruned logs.

3.4 Timber Drying

Fresh sawn boards were each randomly allocated to two stacks for the drying experiment. Stacks were assembled on pallets designed for drying timber that provided airflow underneath, the first layer of sawn timber positioned 15cm from the ground or the stack below. These two stacks were shifted by forklift immediately on completion of sawmilling.

Both stacks were wrapped with a single layer of microclima cloth, a semi-permeable white-coloured cloth used for reducing air flow through the stack. A single 1800 kg concrete slab was placed on top of each stack to weight it.

One stack (the ‘yard drying’ treatment) was positioned outdoors in the drying yard adjacent to the sawmill, sheltered from prevailing winds and on compacted gravel. This stack was positioned between two other timber stacks each of approximately equal height, with a 30 cm gap between stacks to limit air movement. The two ends were open to air movement with no adjacent stacks present. Positioning of stacks simulated a production situation where stacks would be held in reasonably close proximity.

The other stack was positioned inside a drying shed with a concrete floor, corrugated iron roof and slatted walls. The slats covered half the wall area and were installed to limit air flow through the shed. The stack was wrapped with a single layer of microclima cloth and a single 1800 kg concrete slab was placed on top of the stack to weight it.

Both stacks were air dried for 4 months. On April 20th 2013 ten randomly selected boards on the outside of the stacks were measured for moisture content with a Trotec T500 Multi-board Measure Professional resistance method hand-held moisture-measuring instrument. This averaged 19.9% for the shed dried material and 18.73% for the yard dried material. Although it was decided the timber was dry enough to finish drying in the Solarola solar kiln at this point, because of unrelated production constraints the timber was not transferred into the kiln until 20 October 2013. Both stacks were positioned in the kiln as a single charge. The timber stacks were removed from the kiln on 19 November and placed in a fully enclosed concrete floored shed used for storing dry timber.

Steam reconditioning was not performed on the timber.

Boards were measured for moisture content immediately prior to dressing (blanking and profiling) using a Trotec T500 Multi-board Measure Professional resistance method hand-held moisture-measuring instrument. Ten randomly selected boards from both stacks were tested for moisture content, which averaged 12.6%. This moisture content was deemed appropriate for dressing and grading the timber.

3.5 Timber Processing

The nominal 100 mm, 125 mm and 150 mm timber was dressed in two stages, blanking then profiling. Blanking took place on 20th and 21st November 2013 through a Logosol PH 260 four sider to 23 mm thickness and widths to the dimensions in Table 1.

All boards were dressed straight using a straight edge fence. Any crook was edged out by feeding boards through the machine with the concave edge against the fence, removing all crook at the risk of causing skip. Where crook was anticipated to be excessive and likely to result in loss of value as edge skip when profiled, the board was docked to provide shorter lengths for dressing straight. Where knots were observed to cause board distortion, the knot was docked out of the board prior to it being dressed.

Table 1
Nominal and Dressed Board Widths

Board Nominal Width (mm)	Blanked Width (mm)	Profiled Width (mm)
150	155	128
125	125	109
100	96	83
75	72	--
50	48	--

Blanked boards of nominal sizes 100mm, 125mm and 150mm were dressed with a second pass into tongue and groove flooring profile at 19 mm thickness. Each blanked board was evaluated and a decision made on how to feed into the machine, based on levels of surface checking and collapse depth on both faces in an attempt to profile the best surface to the top (exposed) surface of the board. Where possible, excessive collapse or checking on the blanked board was turned down to the bottom face.

Blanked boards of nominal sizes 50mm and 75mm were not dressed further into profile.

3.6 Grading Procedure and Data Inventory

Grading was undertaken in February 2014. Boards were measured for moisture content immediately prior to grading using a Trotec T500 Multi-board Measure Professional resistance method hand-held moisture-measuring instrument.

Ten randomly selected boards from both stacks were tested for moisture content, which averaged 11.75%.

Grading judgement calls took into account the value trade-off between predetermined value assumptions for grade and piece length (see Chapter 3.7). Board positions were marked where the board would be docked. Where possible timber was "docked" to achieve lengths that met equivalent grades under both sets of grading rules being employed.

For every board the following data was recorded:

- Board number;
- tree number;
- log number;
- drying treatment category;
- board nominal width;
- percentage of board length with checks present on the profiled surface;
- sum of length of checks present on the profiled surface; and
- end taper.

Individual boards were marked with a pencil into pieces, then each piece length measured and categorised. Each piece length was allocated to a grade or defect category. Grade and defect categories related to the width of the timber being graded and the grade rules being employed.

3.7 Grading

Grading of boards was undertaken using two sets of rules, Australian Standards AS 2796.2 – 2006 (AS) and Farm Forestry Timbers (FFT) grades as published in Grade Revision 1.1 October 2013 (NZFFA, 2013).

Nominal 75 mm and 50 mm width boards were graded to Farm Forestry Timbers Standards but not to Australian Standards. Profiled nominal 100 mm, 125 mm and 150 mm board lengths were graded to both Australian Standards and Farm Forestry Timbers Standards.

Grading method was assumed to not influence price, with FFT Flooring clears grade holding the same value as AS select grade, FFT Flooring standard grade holding the same value as AS standard grade and FFT Flooring feature grade holding the same value as AS high feature grade.

3.7.1 Grading assumptions

Grading was undertaken based on the following assumptions:

- FFT Flooring overlay is worth 90% of FFT Flooring over-joist grade with the same length and width dimensions.
- Flooring product of 900mm - 1200 mm length is worth 90% of the price of >1200 mm flooring per lineal metre of the same grade and width.
- Flooring product of 600mm - 900mm length is worth 75% of the price of >1200 mm flooring per lineal metre of the same grade and width.
- Flooring product of 300 - 600 mm length is worth 25% of the price of >1200 mm flooring per lineal metre of the same grade and width.
- 125 mm flooring is worth 75% of the price of 150 mm flooring for the same grade and length.
- 100 mm flooring is worth 60% of the price of 150 mm flooring for the same grade and length.
- Standard grade is worth 80% of the price of select or clears grade of the same width and length.

- AS high feature grade is worth 50% of the price of AS select grade of the same width and length.
- FFT Flooring feature grade is worth 50% of the price of FFT Flooring clears grade of the same width and length.
- FFT Panel Laminating grade with length of 300 mm - 1500 mm is worth 50% of the price of >1500 mm length per lineal metre of the same width and grade.
- FFT Panel Laminating grade with four faces clear is worth the same by nominal volume as 150 mm wide FFT Flooring clears grade of the same length.
- FFT Panel Laminating grade with two faces/edges clear is worth 80% of the price of FFT Panel Laminating grade with four faces clear and of the same length and width.
- FFT Panel Laminating grade with one edge clear is worth 70% of the price of FFT Panel Laminating grade with four faces clear and of the same length and width.

3.7.2 Grading flooring product to Australian standards

Profiled nominal 100 mm, 125 mm and 150 mm width boards were graded to Australian Standards 2796.2 – 2006.

3.7.2.1 Defect categories for board pieces

Defect piece lengths were recorded in the following categories:

- End splits defect;
- box defect (Natural feature such as knots that do not meet grade requirements);

- collapse defect (skip);
- skip from wane;
- skip from cupping, twist);
- machining voids and want;
- excessive checks defect;
- tongue defect resulting from straightening out crook from boards;
- tongue defect resulting from collapse shrinkage; and
- piece length within each grade and length category combination.

3.7.2.2 Grade categories for board pieces

Graded piece lengths were recorded and categorised according to the following grades:

1. Select;
2. standard; and
3. high feature.

3.7.2.3 Piece length categories

Graded piece lengths were recorded in the following length categories:

- 300 mm – 600 mm;
- 600 mm – 1200 mm; and
- > 1200 mm.

3.7.3 Grading flooring product to Farm Forestry Timbers standards

Profiled nominal 100 mm, 125 mm and 150 mm width boards were graded to FFT Flooring grades as published in grade revision 1.1 October 2013.

3.7.3.1 Defect categories for board pieces

Defect piece lengths were recorded in the following categories:

- End splits defect;
- box defect (natural feature such as knots that do not meet grade requirements);
- collapse defect (skip);
- skip from wane;
- skip from cupping, twist;
- machining voids and want;
- excessive checks defect;
- grade category for each piece meeting a grade category (clears over joists, standard over joists, feature over joists, clears overlay, standard overlay, feature overlay); and
- piece length for each grade and length category.

3.7.3.2 Grade categories for board pieces

Graded piece lengths were recorded and categorised according to the following grades:

- Clears over joists;
- standard over joists;
- feature over joists;
- clears overlay;
- standard overlay; and
- feature overlay.

3.7.3.3 Piece length categories

Graded piece lengths were recorded in the following length categories:

- 300 mm – 600 mm;
- 600 mm – 1200 mm; and
- > 1200 mm.

3.7.4 Grading of 50 mm and 75 mm nominal width boards

Blanked nominal 75 mm and 50 mm width boards were graded to either FFT Panel Laminating grade as published in Grade revision 1.1 October 2013 or FFT Joinery grade as published in Grade revision 1.1 October 2013.

Grade estimates were made based on expected defect upon final profiling. Levels of checking and natural feature were not altered but skip was measured and an estimate was made of its expected presence or absence on the profiled surface. Sample boards were later dressed to profile immediately prior to laminating into panels because freshly planed surfaces were required for glue adhesion.

3.7.5 Grade interpretations and modifications

Concealed surfaces were graded to meet the structural conditions in both AS grades and FFT Over-joist grades.

Modifications to grade rules for the purposes of this study:

- AS select grade was downgraded to standard grade where checks were present.
- Box included clear short lengths under 30 cm.
- End splits included end checks.

Where wane or skip was present on concealed surfaces this was deemed acceptable provided it did not affect the stability of the boards or the tongue or groove connection.

Where two or more defects were present on a piece to be graded, defects held predetermined priorities. The following category priorities applied:

- End taper held priority over end splits or any other defect.
- End splits held priority over box, skip and other defect.
- Box held priority over skip and excessive checks.
- Excessive checks held priority over collapse defect.

End taper was not categorised as defect, but instead was deducted from green sawn timber recovery and board lengths to be graded. Where end taper could not be distinguished from skip caused by collapse, a judgment call was made and one category selected. Where end taper could not be distinguished from taper caused by machining out crook, a judgment call was made and one category selected.

Where structural requirements for AS grades were not met on concealed surfaces the board or board piece was classed as box defect.

Where structural requirements for FFT Flooring graded over joists were not met on concealed surfaces, the board or board piece was either classed as FFT Flooring overlay or as box defect.

3.7.6 Defect groups

Defect was also divided into two groups:

1. Natural defect:

- Shakes or decay, knots, holes, encased bark, decay, kino and other natural feature that did not meet grade rules (box).

2. Potentially avoidable defect:

   - End splits;
   - pith;
   - mechanical damage (want);
   - wane;
   - skip resulting from collapse;
   - skip resulting from cupping; and
   - severe checking that did not meet grade rules.

3.7.7 Collapse

Collapse defect was recorded where exposed as skip on the profiled surface.

Excessive collapse on the edges of boards was classed as defect where this would result in a weak tongue/groove connection under FFT grade rules. AS grade requirements were specific for tongue and groove connections and levels of skip allowed in tongues and grooves.

Collapse was allowed on the bottom surface of the flooring product where this did not make the board unstable. Both edges of the bottom surface were required to be free of skip.

Collapse skip was estimated on the profiled surface of panel laminating boards because these were graded as a blanked product.

3.7.8 Checks

Boards or board pieces with levels of checks that did not meet grade rules were classed as excessive checks defect.

Checking on concealed surfaces was not measured.

Because grading of boards did not explicitly quantify levels of checking in boards, levels of checks were also measured on profiled exposed surfaces as:

- Percentage of the board length with checks present on the surface cross section perpendicular to the edge.
- Lengths of individual checks, measured over the whole board length (3m) and summed, then averaged per lineal metre.

A check score for each board was then calculated as the average between:

- the percentage of the board's length with checks present; and
- the sum of check lengths per lineal metre.

3.7.8.1 Check score as percentage of log volume

Log volume with checks present was calculated by summing individual board volumes with checks present from that log. The percentage of the log with checks present was then calculated by dividing the total board volume from the log by the volume with checks present.

Summed lengths of individual checks per metre were weighted by volume and summed for each board in the log. Total board volume for the log was divided by this quantity for a percentage value representing lengths of checks in that log.

The percentage values for checks present in the log and lengths of checks in the log were averaged for a check score as a percentage of the log.

3.7.9 Grading to reflect no collapse

Grading was also performed to simulate product grades as if the boards had been steam reconditioned to recover collapse. Where skip caused by collapse was present this was ignored and grade recoveries were adjusted to reflect the scenario where steam reconditioning would have eliminated collapse defect in profiled boards.

For AS grades ignoring collapse, the following data was recorded for every 100 mm, 125 mm and 150 mm board in addition to that recorded for AS grades:

- Tongue defect resulting from straightening crook;
- tongue defect resulting from collapse shrinkage;
- adjusted collapse defect;
- grade category for each piece (select, standard and high feature); and
- individual piece lengths (300 mm – 600 mm, 600 mm – 900 mm, 900 mm – 1200 mm, > 1200 mm.

For FFT grades ignoring collapse, the following data was recorded for every board in addition to that recorded for FFT grades:

- Adjusted collapse defect;
- grade category for each piece (clears, standard and feature); and
- individual piece lengths (300 mm – 600 mm, 600 mm – 900 mm, 900 mm – 1200 mm and > 1200 mm.

3.8 Methods for Assessing Production Costs

Sawmill, drying and processing costs per sawn cubic metre are summarised in Chapter 4.2.5. Methods for estimating processing costs are presented below.

3.8.1 Harvesting costs

Harvesting and logging costs were based on those provided in the Laurie Forestry Ltd Canterbury pricing table (see Appendix A1).

3.8.2 Labour

Labour was classified into two categories, primary and secondary labour. Primary labour was priced higher on the assumption that this person holds responsibility and the secondary labour would hold a support role.

Labour costs were calculated per hour and summed for the labour units participating in an operation (see Appendix A5).

Labour rates were gross per hour including holiday pay. Time for repairs and maintenance was recorded in addition to sawmilling time.

3.8.3 Sawmill costs

Sawmill costs were all converted into per hour costs, except log handling costs, which were estimated per log. Log handling costs included loading the log onto the sawmill bed but not positioning the log on the bed. Positioning the log on the bed and clamping in place were recorded within sawmilling time. Sawmill costs are presented in Appendix A5.

3.8.4 Sawmill asset costs

Purchase prices for equipment were obtained from John Fairweather Specialty Timbers, the case study operation. These were allocated annual straight line depreciation rates as per the operation's accounts. Annual rental costs for equipment were quantified from depreciation plus interest on capital. Interest rate was set as the discount rate used in the discounted cash flow analysis of costs and returns (See Appendix A5).

Costs for sawmill yard were calculated as a rental per hour plus additional costs for repairs and maintenance. Rental costs were converted to an hourly rental cost by dividing annual cost by estimated annual operating hours (See Appendix A5).

3.8.5 Sawmill operating costs

Sawmilling time was recorded per log based on length of time for the Woodmizer bandsaw to slab the log, including positioning of the log on the bed. Log handling costs were recorded separately, as were the cost of band changes.

Two labour units (primary and secondary labour) were recorded as costs for sawmilling, each labour unit operating separate equipment (the bandsaw and edger).

Electricity and fuel were priced per unit. Units consumed were measured for one operating hour. Electricity and fuel costs were calculated per hour by multiplying unit price by units consumed per operating hour.

Woodmizer bands were costed per hour based on $60 for the band, with five sharpens before replacement and two hours service between sharpening.

Band sharpening costs were estimated per hour.

Edger blade costs were estimated based on 1000 operating hours between sharpens and one hour to sharpen for the primary labour unit.

Band changes were estimated to take four minutes, once every two hours for the primary labour unit. This cost was additional to actual sawmilling times recorded for each log and assumes the secondary labour unit would continue with edging during this period.

Hourly costs were converted to per log costs based on time measured to sawmill each log.

Annual costs were allocated to individual logs by assuming 1832 working hours per annum, then converting annual costs to hourly costs. Annual costs included:

- Costs for capital depreciation;
- interest (return on investment); and
- maintenance.

Interest was set as the discount rate. For depreciation rates see Appendix A5.

The sawmill site was converted to an annual expense by estimating the interest payable on the capital value for the land area used (1/4 hectare) as a proportion of the total land holding, plus the rates payable for the area of land used as a proportion of the total land holding. See Appendix A5 for details on sawmill operating costs. Sawmilling cost per nominal sawn cubic metre of production (not including log cost) for each log is presented in Figure 5.

3.8.6 Timber drying costs

Drying costs were estimated per nominal sawn cubic metre of timber, for both yard and shed drying. Log residual values were estimated based on yard drying because this was the less expensive option and the results of the drying experiment (see Chapter 4.3) revealed that no significant differences in quality were evident.

Costs recorded included:

- Shifting the filleted stack from the sawmill into position in the drying yard and replacing the drying pallet beside the sawmill, measured as time for one labour unit to complete the task, then converted to a cost per sawn cubic metre;

- stack preparation (weighting and wrapping), measured as time for one labour unit to complete the task, then converted to a cost per sawn cubic metre;
- drying space as a rental for one year based on setup costs for compacted gravel;
- repairs and maintenance of the drying yard;
- cost of fillets, pallets and concrete weights as a rental;
- cost of microclima wrapping cloth;
- solar kiln;
- site rental (based on capacity of the solar kiln); and
- forklift.

Site rental was calculated from the interest amount payable on the value of 0.5 hectares of land, plus land rates payable per hectare of land. Interest rate was set as the discount rate used in the discounted cash flow analysis of costs and returns in this study. Site rental as a cost per nominal sawn cubic metre of stack was then calculated from the annual kiln capacity, and assuming each stack would be in place in the drying yard for one year.

Drying space for yard drying was calculated as the capital expenditure for constructing a level gravel foundation, as a depreciation expense for the space required for one cubic metre of timber as a filleted stack for one year.

Drying space for shed drying was calculated as the capital expenditure for constructing a drying shed, as a depreciation expense for the space required for one cubic metre of timber as a filleted stack for one year.

Drying costs per nominal sawn cubic metre were summed and converted to a cost per log based on the nominal sawn production from each log.

Timber drying costs are presented in Appendix A6.

3.8.7 Timber processing costs

Processing costs were estimated per nominal sawn cubic metre of timber, per hour and per board lineal metre.

Costs recorded included:

- Shifting the stack into the processing shed (as a cost per cubic metre);
- labour, blanking (as a cost per lineal metre);
- labour, profiling (as a cost per lineal metre);
- labour, grading and docking (as a cost per lineal metre);
- labour, restacking (as a cost per lineal metre);
- despatch and product preparation (as a cost per lineal metre),
- knives, sharpening (as a cost per cubic metre);
- electricity (as a cost per hour and as a cost per lineal metre); and
- boron treatment (as a cost per cubic metre).

Boron treatment was not undertaken but the cost of this per cubic metre was estimated and included for producing timber that meets market requirements.

Per cubic metre processing costs were converted to lineal metre costs for each board width. Cost for blanking and profiling did not vary for different board widths because this was based on a rate per lineal metre fed through the machine. Machining costs were then calculated per log based on the lineal metres of sawn timber produced from the log.

Timber processing costs are presented in Appendix A7.

3.8.8 Steam reconditioning scenario

Under this scenario steam reconditioning was assumed to have taken place. The additional cost of steam reconditioning (see Appendix A6) was included as a processing cost and defect from collapse was assumed to not be present on profiled, graded surfaces.

3.8.9 Marketing, management and overhead cost

Marketing, management and overhead cost for the case study processing operation was specified as 10% of sawn timber revenue. This cost represents profit for the processing operation in addition to return on investment.

3.9 Drying Experiment

If drying outdoors produced no more drying degrade than shed drying, this would be the preferable method in economic terms because of lower costs. An experiment was designed to compare these two methods to determine best practice as an economic analysis.

This study design was:

- For slow air drying from green with finishing in a solar kiln;
- to wrap stacks with permeable cloth to slow air flow through the stacks; and
- to compare sawn timber value from shed air drying with outdoors air drying.

Board prices resulting from two different drying methods, air drying outdoors and air drying in a drying shed, were compared. Board grade recoveries could not be directly compared because grading decisions are based on judgement calls that consider the value compromise between shorter lengths of higher grades and longer lengths of lower grades.

Individual board prices were calculated by summing the prices for each piece within the board that met a grade. Pieces were priced according to the length of the piece multiplied by the price of the profile allocated to the piece. The price for each profile was determined by the grade, length and width categories.

Grading of boards was undertaken before board profiles were priced from survey results. Therefore, arbitrary discounts and premiums for board profiles were set in advance of grading, on which grading judgement calls were based.

3.9.1 Board prices used for drying experiment

Price discounts were set for board profiles based on a reference profile of select grade, 150 mm width, > 1.2 m length. Price discounts were applied to board lengths, widths and grades according to the assumptions used for grading the boards (Chapter 3.7.1).

Discounts for each profile were summed from discounts for each characteristic level present in the profile. The discount was then applied to the profile, revealing a price per lineal metre for that profile.

3.9.2 Statistical analysis

Individual board prices were compared between the two drying treatments and according to tree and log position. The *R* statistical software package was used for analysis of variance (ANOVA). Because log position within tree is not a random variable a mixed effects model was applied to determine probability of rejecting the null hypothesis that there was no difference between drying treatments.

3.10 Revenues

Revenues were estimated for each sample log processed. Because sales data was not available for *E. nitens* products in order to estimate revenues used for calculating log residual value, an alternative approach was taken to estimate product prices.

3.10.1 Sawn timber revenues

Satchell (2015) reported price discounts and premiums for levels of quality characteristics corresponding to the same flooring timber categories that sawn timber from this study was graded into. These discounts and premiums were aggregated into prices per lineal metre of sawn timber, presented in Appendix D (Table 35 and Table 36). For sawn lengths less than 1.2 m, graded pairs comparison prices were further discounted for residual product values as:

- The cost of end-jointing for 30 cm - 60 cm lengths (see Appendix A7); or
- the cost of end-matching for 60 cm - 120 cm lengths (See Appendix A7).

This produced product residual values for boards less than 1.2 m length for the graded-pairs pricing method.

3.10.2 Product residual values - laminated panels

Two laminated panels were produced to generate residual value price estimates for the 50 mm and 75 mm wide timber feedstock graded to FFT panel-laminated and FFT joinery grades. Nominal 75 mm boards were laminated according to the grades allocated to the blanked surfaces and the two length categories. Grading was to Farm Forestry Timbers (FFT) panel laminating grade clear one face as published in Grade revision 1.1 October 2013.

One 3 m long panel was made from 3 m lengths graded to clear one face (i.e. with no buttjoins in the panel). Thirty-eight full length (3m) blanked nominal 75mm width boards graded to clear one face were marked on one end for the graded clear edge and the best end. The intention was to produce a panel with the clear edge on the exposed surface and with one end suitable for a defect-free appearance application.

The other 3 m long panel was made from 300 mm - 1500 mm lengths graded to clear one face (i.e. with buttjoins exposed on the surface of the panel) and with the clear edge marked for the exposed surface. The intention was to produce a lower quality panel with a defect-free “clears” surface suitable for appearance applications but with exposed joints on the surface.

The two panels were assembled by A. J. Wang, Christchurch. The boards were dressed from 23 mm to 19 mm thickness and immediately glue-laminated into panels according to the marks provided. The panels were sanded on both faces and two panels were produced, each of 60 mm thickness. The panel made from 3 m lengths was finished to 730 mm width and the panel made from short lengths was finished to 560 mm width.

Both panels were then coated with sanding sealer and sold.

Costs for preparing and laminating the panels were quantified for each panel (See Appendix A3). The panels were sold to determine market prices for the two panel products, each of different quality. Board prices were then calculated as a residual value by subtracting costs from sale price and converting net revenue to a per-lineal metre for the input timber product.

In calculating residual values for panels, price was assumed to not vary per product cubic metre between panels of finished 60 mm and 40 mm thickness, nor according to panel width. Price for FFT panel laminating clear two faces grade and FFT Joinery clears grade was assumed to be the same as for FFT panel laminating clear one face grade.

Prices for 75 mm and 50 mm width boards were calculated as residual values from the sales prices of laminated panels and the costs of producing these. These prices are presented in Appendix D (Table 37).

3.10.3 Sample log sawn timber revenue

Board piece prices were calculated by multiplying each graded board piece length by the price allocated to its profile per lineal metre. These board piece monetary values were then summed for the resulting board price. Sawn timber revenue for each sample sawlog was calculated by summing board price estimates for each log.

3.10.4 Secondary product revenues

Prices for sawdust and slab firewood were estimated as sawmill gate sales (see Appendix A2). Quantities from sample logs were estimated as percentages of total log volume.

3.11 Predicting Plot Log Costs and Revenues

The *R* statistical software package was used for predicting plot log costs and revenues from the sample log values. A linear mixed effects model was fitted using the lme class to take into account that log position number is not random. Where percentages were the response variable these were normalised using arcsine transformation. A quadratic (second degree) polynomial linear mixed effects model provided a better fit than a straight linear model to explain nominal sawn recovery according to SED, sawmilling cost per nominal sawn cubic metre of production according to SED, sawmilling costs per log cubic metre and yard drying costs per log cubic metre.

Where sawn timber revenues and sawn timber residual values were not significantly different to the 5% significance level, the average value was used.

3.12 Cash Flows

The discount rate was set as 8.5% and this was also the rate of return on processing capital. All costs and revenues were discounted to year 0 for a Net Present Value (NPV).

3.12.1 Grower revenues

Pulpwood/firewood log sales occurred at the time of harvest (15 years from planting).

Slab firewood and sawdust sales occurred at year 16.

Sawn timber revenue occurred at year 16.

3.12.2 Growing and harvesting costs

Site preparation, plant stock and planting costs were recorded for year 0, releasing costs year 1, pruning costs year 3 and year 5, and thinning costs year 10. Land rental and annual growing costs were recorded for year 1 through to year 15 (See Appendix A1).

Logging, loading and transport costs occurred at the time of harvest (15 years from planting) and under the base scenario (see Appendix A1).

3.13 *E. nitens* physical properties

A range of physical properties were tested to examine the potential influence these could have on sawn timber value for 15 year old *E. nitens* and to conduct statistical comparisons between properties and other log characteristics that could influence log value.

3.13.1 Dry board and log density assessment

Profiled tongue and groove kiln dried boards were weighed with Wedderburn WS 201-10k scales (d=0.0005kg). Board volume was calculated as end cross section area multiplied by length. Board length was noted and a length reduction was estimated where wane was present.

Dry log density was estimated by summing board weights and dividing by total board volume. Log dry densities were calculated for all logs.

3.13.2 *E. nitens* sample physical properties

A single sample section of 0.6 m length with no obvious feature was docked from a randomly selected blanked 125 mm width board from each *E. nitens* log.

All samples were sent to Scion Rotorua and were tested for the following physical properties:

- Density;
- hardness; and
- long term movement in service.

3.13.2.1 Hardness

Samples were all tested twice on one face for Janka hardness and these results averaged.

3.13.2.2 Movement in service

All samples were tested for long-term dimensional stability. Long-term movement is expressed as the percentage of movement occurring across the width of the board when the moisture content changes from equilibrium at 85% RH to equilibrium at 35% RH.

Samples were prepared into test samples that were 70 mm wide, 50 mm long and 10 mm thick. Long-term movement was assessed by equalising standard sized samples in conditions of 25°C and 85% relative humidity. When the samples were at equilibrium (determined by having a stable mass) the samples were weighed and width and length were measured. The samples were then exposed to conditions of 25°C and 35% relative humidity. When the samples again reached equilibrium they were weighed and the width and length remeasured. The difference between the two width measurements was calculated as a percentage of the width in the 35% humidity conditions. The classification system categorises sum of radial and tangential movements as:

- Small <3.0 %
- Medium 3.0 – 4.5 %
- Large >4.5 %

3.13.2.3 Sample densities

Density was measured for all samples at test by weighing a sample cut from the test piece immediately after testing for hardness. The sample was oven dried at a temperature of 103 degrees Celsius until the weight was constant. The samples were weighed again and the weight loss was divided by the final oven dry weight and expressed as percentage moisture content for the test samples at test.

3.14 Scope and Limitations of the Study

This case study was intended as a pilot investigation to explore potential profitability of growing *E. nitens* for solid timber products from a 15-year-old pruned and thinned stand of *E. nitens* grown in the Canterbury Plains near Rangiora. Methods applied to this investigation into profitability of growing *E. nitens* for sawn timber had a range of constraints that did not allow generalisations to be made for the species. These limitations narrow the scope to that of a case study and are described in this section.

3.14.1 The case study stand

Sawn wood quality and timber values were assessed from a sample of eight trees. The small sample size is acknowledged as a limitation to applying sawn timber production results wider than to the case study itself.

Tree and log volumes were estimated for every tree in the case study stand. However, the small size of the stand (55 trees in two closely adjoining but not contiguous areas) allowed for only two small plots (each 28 m x 8 m) that excluded edge trees, for estimating quantities from a larger hypothetical stand. The small size of this stand precluded standard methods for quantifying volumes per hectare from sample plots and is acknowledged as a limitation to applying yield results wider than to the case study stand itself.

Sample trees were selected for sawing to represent the range of diameters present inside the stand. Although no bias in such selection was evident apart from specific diameter requirements that represented the range of trees found within the stand and avoidance of edge trees, because sample trees were not randomly selected, these cannot strictly be generalised as representative of the stand population.

This study was intended to pilot methods for assessing *E. nitens* log residual value that could be standardised in more comprehensive future research. Wood properties would be expected to vary between trees, regions and even under different site conditions within a region. Thus relationships observed from sample sawlogs from this case study would need to be verified by additional research findings before these could be generalised to a wider population.

3.14.2 Secondary products

Sawdust weight was estimated as the remainder from the total weight of all logs after deducting the estimated weight of sawn boards (based on measured volume production and estimated log density) and weight of slabwood. However, sawdust is likely to be sold on a volume basis and estimating volumes from weight is problematic because these rapidly change as the sawdust dries or compacts. Therefore the volume estimate of sawdust produced in the study may not accurately reflect real volumes.

Slabwood is automatically fed through a firewood-cutting machine as part of the sawmilling operation. Although for the purposes of this study slabwood was put aside and weighed to estimate its volume, a conversion factor (see Appendix A2) was required from log volume estimates for then valuing the resulting firewood per 'thrown' cubic metre. This factor as practiced by the firewood industry could be adjusted for applying to slab firewood from specific processing equipment because average piece sizes of firewood produced from different equipment will produce varying volumes of wood as a 'thrown' cubic metre of volume.

3.14.3 Pulpwood vs. firewood

Because Canterbury has no established hardwood chipwood market, *E. nitens* logs are typically utilised for firewood only. Market prices are likely to vary considerably between stumpages for firewood in Canterbury and in regions where a hardwood chipwood market is in operation. In this economic evaluation, under the base scenario logs under 25 cm diameter were priced and sold as firewood logs (see Appendix A2).

3.14.4 Processing

All recoveries and values were for logs specifically cross cut to 3 m lengths. Although assumed to be the optimal length for the processing equipment employed, this length is arbitrary rather than optimised through specific research.

Sawmilling of logs was undertaken with one set of machinery, a Woodmizer LT 40 horizontal bandsaw and Woodmizer twin-blade edger, both petrol-operated. The equipment was selected for this study because it is suitable for efficient small scale eucalypt processing (Satchell & Turner, 2010) and only requires investment to the level required for the initial stages of emerging an industry.

The author performed all edging of slabs. The consequence of limited experience at this task may have resulted in variability of grade-sawn output volumes.

A more experienced and skilled operator might have produced more consistent and improved grade recoveries from those documented in this study.

The air-dry sawn timber from this case study was kiln dried using a Solarola Mini-Pro Sun-dry Kiln (6 m^3 capacity). This is the smallest of a range of commercial kilns and the manufacturer subsequent to purchase of this kiln advised the owner that the relatively low timber mass being dried limits this kiln's effectiveness and reduces its cost efficiency when compared with larger kilns in the Solarola range (J. Fairweather pers. comm.). The kiln puts through six charges per year in Canterbury conditions. Comparative cost per cubic metre of throughput could not be compared for the Solarola range in Canterbury conditions.

Dressing of timber was undertaken using a Logosol PH 260 four-sider with variable feed speed. Blanking and profiling was accomplished in two stages. This machinery is considered marginal for commercial applications (J Fairweather, pers. comm.) and has a slow feed speed compared with more expensive commercial machines.

An attempt was made to record productivity and costs for the case-study operation under normal operating conditions through all processing stages. This was problematic because the operation itself was under development and was not yet running at commercial capacity during the course of this study.

3.14.5 Harvesting, loading and logging

Harvesting, logging and loading and transport costs were extracted from Laurie Forestry's website (Laurie Forestry, 2014). Laurie Forestry Ltd are harvesting and marketing managers based in Canterbury. Harvesting costs are stated on the website to vary and the logging cost assumptions are to be taken as a guide only (Laurie Forestry, 2014):

> Logging and Loading costs are based on typical operations without undue complexity, which could include the likes of poor wood quality and all weather access being available. Cartage costs are based on averaging of previous quarter.

Logging and Loading costs were based on terrain being easy flat and cartage costs were based on a distance of 50 km from forest to sawmill.

Estimates of log volumes were converted to tonnages per hectare of sawlogs and pulp/firewood logs based on a conversion factor calculated from the weights and volume estimates of the sample logs. The accuracy of this conversion factor was not verified. Because log weights were likely overestimated this would increase transport costs per log cubic metre. All other results would not have been affected by this assumption.

3.14.6 Products

Products assumed to be most profitable for producing from the case study 15 year old *E. nitens* timber were decided in advance. It is acknowledged that these products and the resulting log residual value benchmark is somewhat arbitrary because only over time would production and product choices be refined based on an improved understanding of wood properties and market demand to yield greatest returns.

Solid timber strip flooring was selected as the target product for processing from case study logs for the purpose of determining log residual value. This was assumed to be the most marketable and least risky product to produce and price. The market is negligible for flooring board widths under 100 mm, so the product selected for 75 mm and 50 mm board widths was laminated appearance panels.

Slabwood produced from sawmilling comprises over 50% of the log volume. The firewood by-product produced by the case study operation is assumed to be the most profitable product from slabwood. This is produced at low cost as part of the operation.

3.14.7 Product pricing

In the absence of available market price data for *E. nitens* timber, product value estimates were the proxy for market prices based on sales. These estimates were from comparisons with existing similar products and accuracy could not be verified because market prices were unavailable.

Consistency of supply is a prerequisite for market development of emerging plantation eucalypt timbers (Shield, 1995, p. 136). For price estimates of *E. nitens* timber to be based on an established species and market, consistency of supply needed to be assumed. The importance of this assumption on market price for timber would depend on the scale of an industry supplying *E. nitens* timber. A small industry supplying a niche market would not need to supply timber consistently, whereas a developing industry that requires growth in demand would need to consistently meet that demand. This would be a challenge for growers. Market development, if not steady, would likely result in price fluctuations and thus returns potentially lower than estimated.

3.14.8 Laminated panels

Two laminated panels were produced and sold to ascertain costs and value of the resulting case study product. Prices for the panel laminated timber stock were based on the quality and prices of the two panels produced. These prices may not reflect true market value for this product because of the small sample sold.

3.14.9 Grades and grading

Grades for 100 mm, 125 mm and 150 mm boards were assessed from profiled tongue and groove product. Grades for 75 mm and 50 mm wide boards were estimated from blanked surfaces. Blanked surfaces may not expose all defect or degrade and resulting grades and prices would be less accurate than grading of profiled surfaces.

3.14.10 Degrade

Where checking exceeded grade limits this was classed as defect, but any loss in value caused by checking degrade was not specifically quantified. Future work with a specific focus on reducing checking might require assignment of economic value to checking degrade but this was outside the scope of this study.

3.14.11 Definition of checking degrade

Distinguishing internal checking from surface checking is subjective because internal checks become surface checks if exposed during machining. Definitions of what are surface checks and what are internal checks have not yet been standardised. For example deep surface checks could be defined as internal checks. Definitions for checking in this study are as follows:

- Surface checking**:** 'Surface checking' is defined as either shallow checks that are seen on the surface of rough sawn timber and do not necessarily dress out on profiling, or checks less than 2mm deep and less than 1mm wide on the 19mm profiled surface.

- Internal checking**:** 'Internal checking' is defined as where the check goes in from the surface more than 2mm on the 19mm profiled product on the cross section surface, or where the checks are inside the edge of the cross section surface.

3.14.12 Grading to ignore collapse

The timber was not steam reconditioned. This was a deliberate approach to facilitate accurate measurement of checking levels and defect from collapse, but required assumptions on expected grade recoveries had the timber been steam reconditioned as per standard practice in Australia for ash eucalypt. It was assumed for the purposes of this study that steam reconditioning would have removed all collapse from nominal 25 mm sawn timber sawn at a green size of 28 mm once dressed to 19 mm. Based on this assumption graded timber was re-graded on the premise that skip caused by collapse was not present. If this assumption were to be refuted the methods used for estimating levels of checking would need to be revised.

3.14.13 Wood physical properties

Testing of *E. nitens* physical properties was undertaken from only one sample per log due to budget constraints. The intention was to examine indicative relationships that before being generalised as representative of the species, would require further testing.

3.15 Conclusions

Methods were developed for estimating log volumes per hectare for the case study stand according to log categories.

Methods were developed for quantifying production costs, sawn timber recoveries, grade recoveries and defect from sample logs and sample trees. Grade recoveries were priced to yield an estimate of revenue for each sample log. These were categorised according to tree and log position in the tree. Residual values were calculated for the sample logs.

Spreadsheets were developed and statistical tools used to model production costs and log revenues according to log diameter and log position.

Chapter 4

Results

This section presents results from analysis of growth, production and pricing data for *E. nitens* solid timber production from 15 year-old case study trees. Net present value per hectare was calculated from estimates of sawlog residual values and secondary product prices along with costs for the grower. The results are presented in seven parts:

1. Case study inventory: Log volume and diameter profiles for the two plots in the case study stand;
2. Product results: Sawn recoveries, product volumes, costs, grades, widths and lengths and defect levels produced from the sample logs according to log position;
3. Air-drying experiment: The relative influence on price of air drying in a drying shed compared with drying outdoors;
4. Product profiles: Product value estimates from two survey pricing methods;
5. Log pricing models and cash flows: Cost and revenue estimates according to log diameter from sample logs as log residual value and application of these to inventory logs; Results and analysis of cash flows according to pricing and grading methods;
6. Sensitivity analysis: Economic outcomes according to scenarios, including exclusion of collapse defect, alternative secondary product price estimates and land value; and
7. Improving grade recoveries: A summary of results that offer opportunities for log position to become a driver of sawlog price for *E. nitens.*

Parts one through to three summarise the data used in part five for pricing models. Part four tests the null hypothesis that air drying method does not influence product prices. Parts five to seven provide an economic analysis of the data from parts one to four. Part eight summarises data on grade recoveries and defect according to log position.

4.1 Case Study Stand Inventory

Diameter and height measurements for all fifty-five trees in the Case Study stand were measured and are presented in Figure 1.

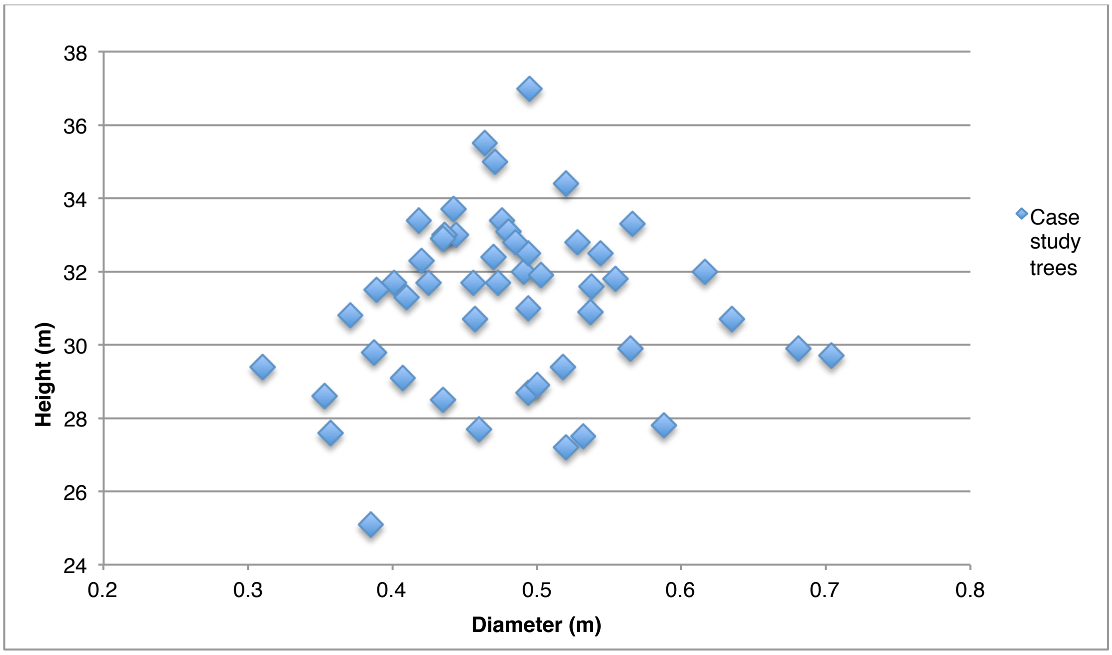

Figure 1. *E. nitens case study stand individual trees, height and diameter*.

A scale diagram of the case study stand (See Appendix B) was produced on which two plots of 224 m^2 each (8 m x 28 m) were positioned that included a total of 21 trees and excluded edge trees. Plot data is presented in Table 2. Diameters and heights of all plot trees are presented in Figure 2 along with the diameters and heights of all sample trees that were harvested and processed.

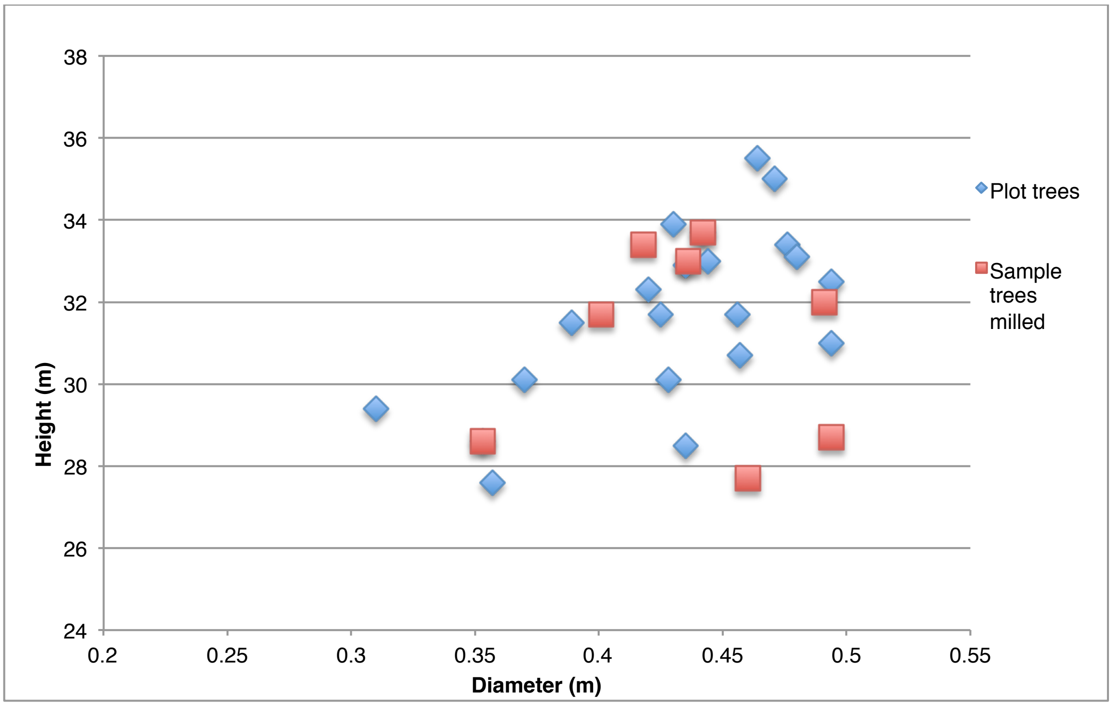

Figure 2. *Plot and sample trees showing heights and diameters.*

4.1.1 Plot log volumes

Plots were positioned to avoid edge trees. Edge trees were observed to be larger than trees within the stand and thus not representative of trees within a larger stand for the purpose of deriving per hectare values. Table 2 presents comparisons of selected values from stand trees.

Table 2
Plot and Stand Data

	Average Basal Area per Tree (m^2)	Average Stem Volume per Tree (m^3)	Average DBH Over Bark (cm)	Average Tree Height (m)	Average Sawlog SED (cm)	Average Sawlogs per tree >25cm SED
Plot Trees	0.124	1.50	43.03	31.24	32.94	3.87
Stand Trees	0.156	1.83	47.73	31.75	35.28	4.38

Table 3 presents quantities from the two plots and scales the plot average for each value to per hectare estimates. Sawlogs were categorised as those logs larger than 25 cm SED and pulp logs were categorised as logs between 10 cm and 25 cm SED. All logs were 3 m length.

Table 3
Plot Data

	Trees	Basal Area (m^2)	Stem Volume (m^3)	Merchantable Volume (m^3)	Buttlog Volume (m^3)	Headlog Volume (m^3)	Pulp-wood Volume (m^3)
Plot 1	11	1.34	15.92	15.55	7.17	4.43	3.94
Plot 2	10	1.27	15.47	15.15	6.78	4.90	3.47
Plot Average	10.5	1.31	15.69	15.35	6.98	4.67	3.71
Per Hectare	469	58.29	700.54	685.20	311.46	208.29	165.45
Average as Percentage of Total	--	--	100 %	98 %	44.5 %	29.7 %	23.6 %

Log volume estimates averaged between plots and scaled to per-hectare values and categorised according to SEDs in 5 cm increments are presented in Figure 3.

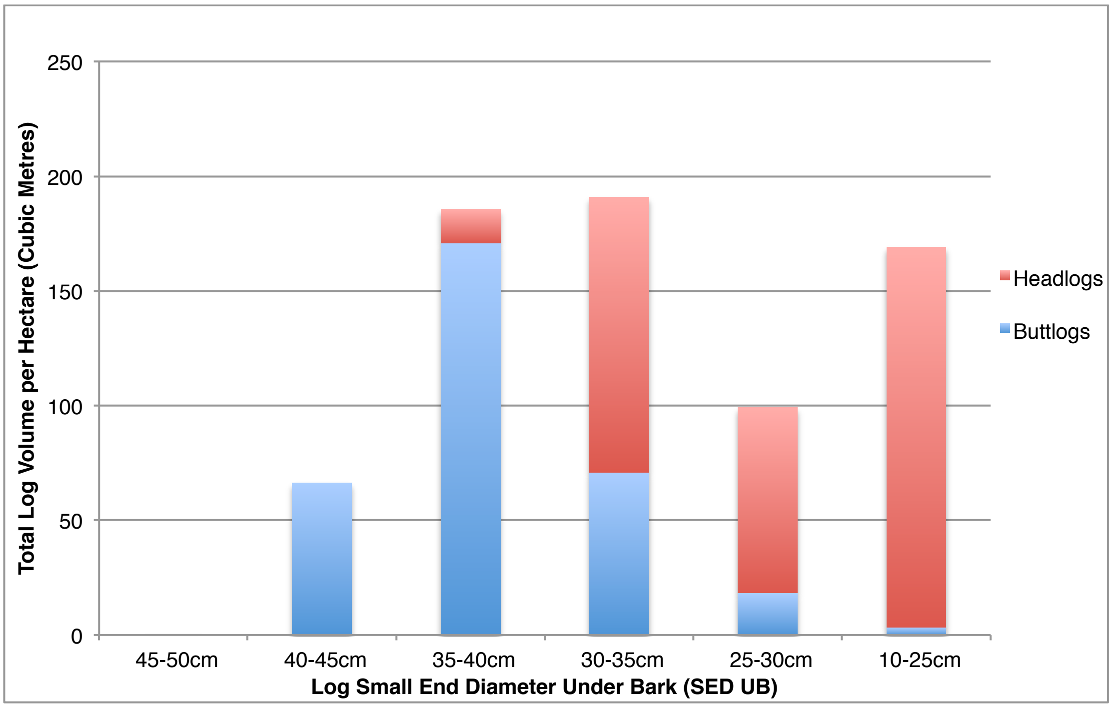

Figure 3. *Estimated volume recoveries per hectare as diameter categories.*

4.2 Production Results

Sample trees were harvested and cross cut into sample logs, which were processed into sawn timber products. Results from the sample logs provided models for predicting costs and revenues for plot trees and hypothetical values per hectare.

4.2.1 Sample log volumes and weights

Green log density at harvest was estimated from sawlog total volume using the Smalian formula and recorded weight of the sample logs:

- Total weight of sample logs = 12.68 tonnes.
- Total volume of sample logs = 10.34 cubic metres.
- Estimated log density per cubic metre (green) = 1.23 tonnes.

4.2.2 Product quantities from sawlogs

Percentage of overall sawlog green weight allocated to products and by-products was estimated as percentage of total weight (in green condition). Slabwood weighed 38% of total green weight. Based on volume of sawn timber and estimated volume per cubic metre, green weight of sawn boards was estimated to be 48% of total green log weight. Assuming sawdust is the residue, sawdust by-product weight was estimated as 14% of total green log weight.

Total nominal sawn timber production from sample logs was 4.06 m^3, with headlogs producing 42.72 % of sawn timber (1.74 m^3) and buttlogs producing 57.28 % (2.33 m^3) of sawn timber.

4.2.3 Sawmill efficiency

Sawn timber recovery as a percentage was found to have a statistically significant relationship ($P = 0.001$) with log small end diameter for the Woodmizer equipment and sample logs. The best fit was a second degree polynomial regression, presented in Figure 4.

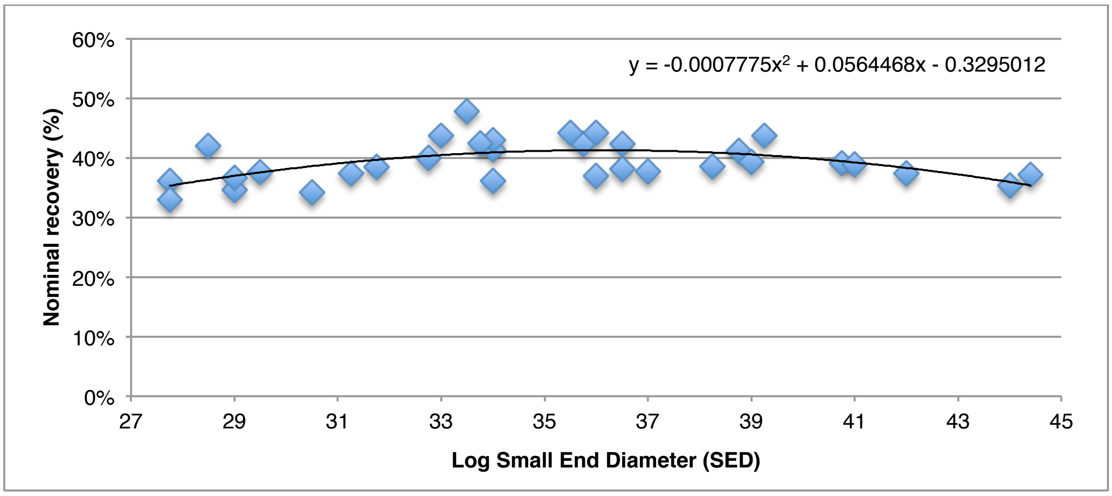

Figure 4. *Nominal sawn timber recoveries according to log small end diameter.*

Sawmilling cost per nominal sawn cubic metre held a statistically significant relationship ($P = 0.0012$) with SED and the second degree polynomial regression curve revealed an optimal diameter range of between approximately 35 cm SED and 42 cm SED for this equipment. The relationship is presented in Figure 5.

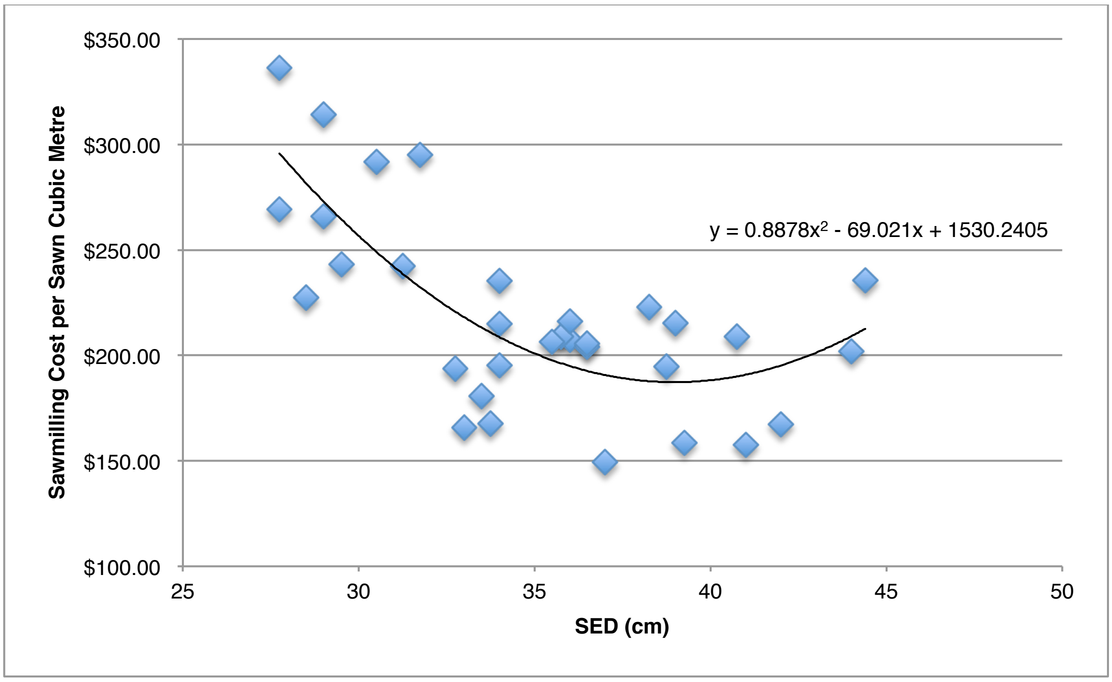

Figure 5. *Sawmilling cost per nominal sawn cubic metre of production (not including log cost).*

4.2.4 Sawn product quantities

Product nominal lengths and widths produced from unpruned headlogs are presented in Table 4 and Table 5. Product nominal lengths and widths produced from pruned buttlogs are presented in Table 6 and Table 7.

Table 4
Product Recoveries as Percentage of Sawn Volume for Nominal 100 mm, 125 mm and 150 mm Widths from Unpruned Headlogs (Logs 3 - 5)

Product	Clears/Select Grade	Standard Grade	Feature/High Feature Grade
300 - 600 mm Length	2.25 %	0.14 %	0 %
600 - 1200 mm Length	8.05 %	1.34 %	1.73 %
> 1200 mm Length	35.14 %	10.41 %	7.31 %

Table 5
Product Recoveries by Volume for 75 mm and 50 mm Widths from Unpruned Headlogs (logs 3 - 5)

Product	Four Faces Clear	Two Faces Clear	One Face Clear
300 - 1500 mm Length	1.98 %	0 %	2.76 %
> 1500 mm Length	7.21 %	1.16 %	10.31 %

Table 6
Product Recoveries as Percentage of Sawn Volume for Nominal 100 mm, 125 mm and 150 mm Widths from Pruned Buttlogs (Logs 1 - 2)

Product	Clears/Select Grade	Standard Grade	Feature/High Feature Grade
300 - 600 mm Length	0.64 %	0.23 %	0 %
600 - 1200 mm Length	2.95 %	1.35 %	0.66 %
> 1200 mm Length	62.7 %	3.39 %	2.42 %

Table 7
Product Recoveries by Volume for 75 mm and 50 mm Widths from Pruned Buttlogs (logs 1 - 2)

Product	Four Faces Clear	Two Faces Clear	One Face Clear
300 - 1500 mm Length	0.12 %	0.2 %	0.05 %
> 1500 mm Length	4.86 %	0.23 %	1.78 %

4.2.5 Processing costs

Results from processing logs into sawn timber products are presented as sawmill costs, drying costs and processing costs, each process being independent but contributory to overall product costs and thus residual value.

Sawmill costs amounted to $89.75 per hour of operation. Sawmill costs per sawn cubic metre are in Figure 5 and sawmill costs per log cubic metre are in Figure 10.

Drying cost estimates per nominal sawn cubic metre were:

- Yard air dried = $202.28.
- Shed air dried = $231.66.
- Steam reconditioning = $30.00.

Machining costs included both a fixed cost per nominal cubic metre of production plus a variable cost per lineal metre (for all widths) of production:

- Cost per cubic metre = $73.86 (includes boron treatment)
- Cost per lineal metre = $0.41

4.2.6 Production volume

Volume of production influences costs per unit of volume output. Annual production volume estimates for the case study sawmilling operation were based on a full time operation, or 229 days per year at 8 hours per day. Annual production volume estimates for the case study processing operation were:

- Sawmill production = 756.85 cubic metres; and
- Machining production = 171,750 lineal metres.

4.2.7 Defect in sawn boards

Table 8
Defect as Percentage of Nominal Sawn Recoveries for All Logs

Defect Category	Farm Forestry Timbers Grading	Farm Forestry Timbers Grading, Ignore Collapse	Australian Standards Grading	Australian Standards Grading, Ignore Collapse
End splits	3.60 %	3.60 %	3.60 %	3.60 %
Collapse	4.60 %	0.00 %	5.46 %	0.00 %
Wane[a]	0.07 %	0.07 %	0.07 %	0.07 %
Skip[b]	0.20 %	0.20 %	0.33 %	0.33 %
Want[c]	0.20 %	0.20 %	0.20 %	0.20 %
Checks[d]	1.78 %	1.78 %	3.0 %	3.0 %
Box[e]	3.59 %	3.59 %	3.81 %	3.81 %
Tongue Crook	0 %	0%	0.13 %	0.05 %
Tongue Collapse	0 %	0 %	0.86 %	0.00 %
Total	14.04 %	9.44 %	16.47 %	10.93 %

[a]Wane: End Taper and End Wane was docked but not classed as recovered sawn timber volume.

[b]Skip: Skip resulting from board cupping, edge wane, face wane and twist.

[c]Want: Want included machining voids such as chipping.

[d]Checks: Box defect caused by excessive checking not meeting grade rules.

[e]Box: Natural defect such as knots and holes that do not meet grade rules.

The level of defect present in sawn boards had an influence over log residual value. Defect was quantified and categorised during grading and is presented in Table 8 as percentages of nominal sawn timber recoveries for each of the two grading methods used, both including and excluding collapse defect.

4.2.8 Grade recoveries

Grade recoveries for all sawn timber widths as a percentage of total nominal recoveries of sawn timber for Farm Forestry Timbers grades totalled to 85.94%, and ignoring collapse defect totalled 90.53%.

Table 9
Grade Recoveries for 100 mm, 125 mm and 150 mm widths as Percentage of Nominal Recoveries for All Logs

Grade and Length	Farm Forestry Timbers Grade	Farm Forestry Timbers Grade, Ignore Collapse	Australian Standards Grade	Australian Standards Grade, Ignore Collapse
Select/Clears 300 - 600 mm	1.31 %	1.15 %	1.72 %	1.53 %
Select/Clears 600 - 1200	5.12 %	5.26 %	5.61 %	5.58 %
Select/Clears >1200 mm	50.71 %	52.61 %	50.7 %	52.99 %
Standard 300 - 600 mm	0.21 %	0.14 %	0.25 %	0.22 %
Standard 600 - 1200 mm	1.29 %	1.33 %	1.28 %	1.3 %
Standard > 1200 mm	6.26 %	6.98 %	6.08 %	7.16 %
Feature/High Feature 300 - 600	--	--	0.03 %	0.03 %
Feature/High Feature 600 - 1200 mm	1.36 %	1.39 %	1.03 %	1.23 %
Feature/High Feature > 1200 mm	5.57 %	5.67 %	1.89 %	2.25 %
Total	71.83 %	74.53 %	68.59 %	72.29 %

Table 9 presents grade recoveries for 100 mm, 125 mm and 150 mm width boards and Table 10 presents grade recoveries for 50 mm and 75 mm width boards.

Table 10
Grade Recoveries for 50 mm and 75 mm widths as Percentage of Nominal Recoveries for All Logs

Length	FFT Panel Lam and Joinery grade	FFT Panel Lam and Joinery Grade, Ignore Collapse
Two Faces Clear 300 - 1500 mm	0.12 %	0.12 %
Two Faces Clear > 1500 mm	0.62 %	0.76 %
One Face Clear 300 - 1500 mm	1.21 %	1.10 %
One Face Clear > 1500 mm	5.43 %	6.13 %
Four Faces Clear 300 - 1500 mm	0.91 %	0.91 %
Four Faces Clear > 1500 mm	5.82 %	6.98 %
Total	14.11 %	16.0 %

4.3 Drying Experiment

Results from analysis of variance show no significant difference between drying treatments and that the null hypothesis that the two treatments are equal cannot be rejected (P=0.7531). Box and whisker plots are presented in Figure 6 for collapse defect and Figure 7 for check scores on the profiled surfaces.

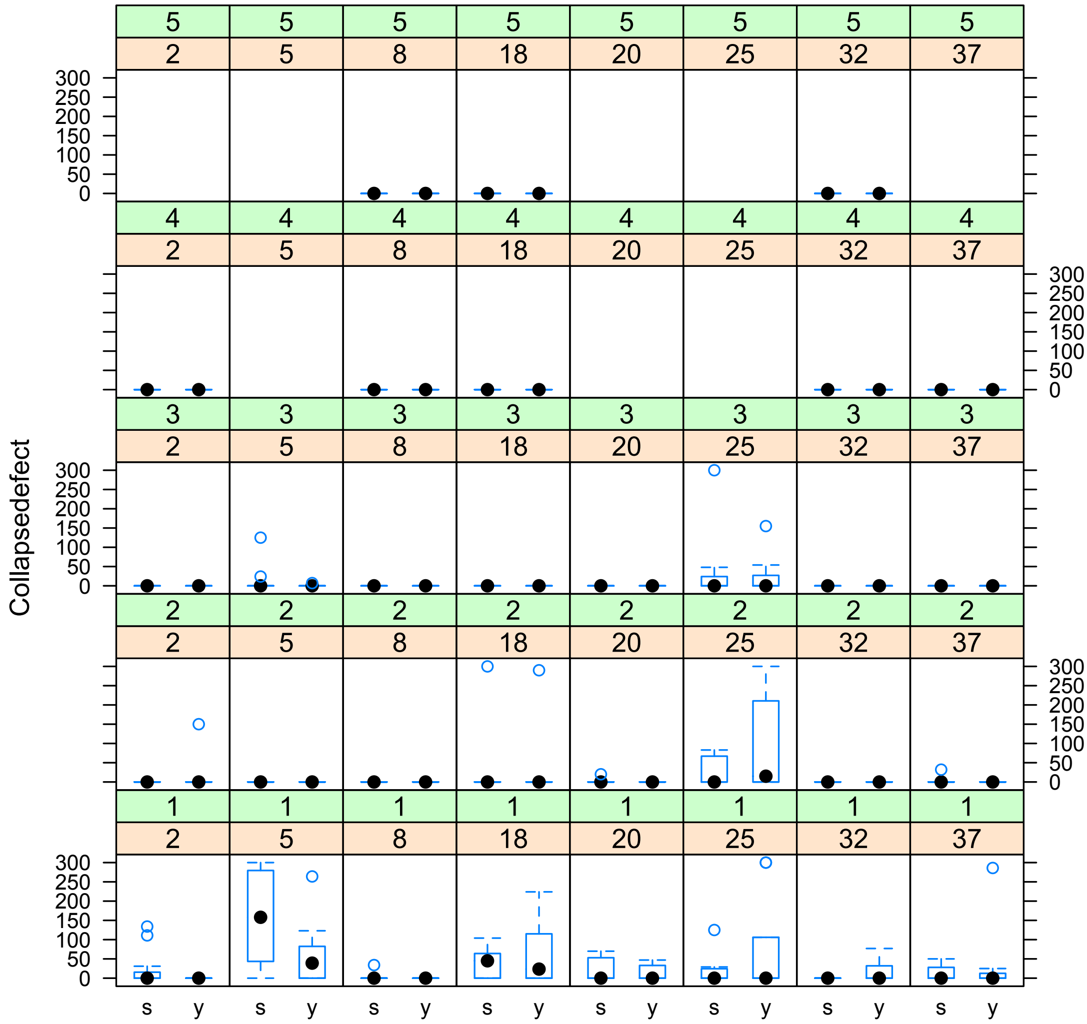

Figure 6. *Collapse defect levels and standard deviations for collapse defect in boards for trees and logs according to drying treatment (Y=yard drying, S= shed drying).*

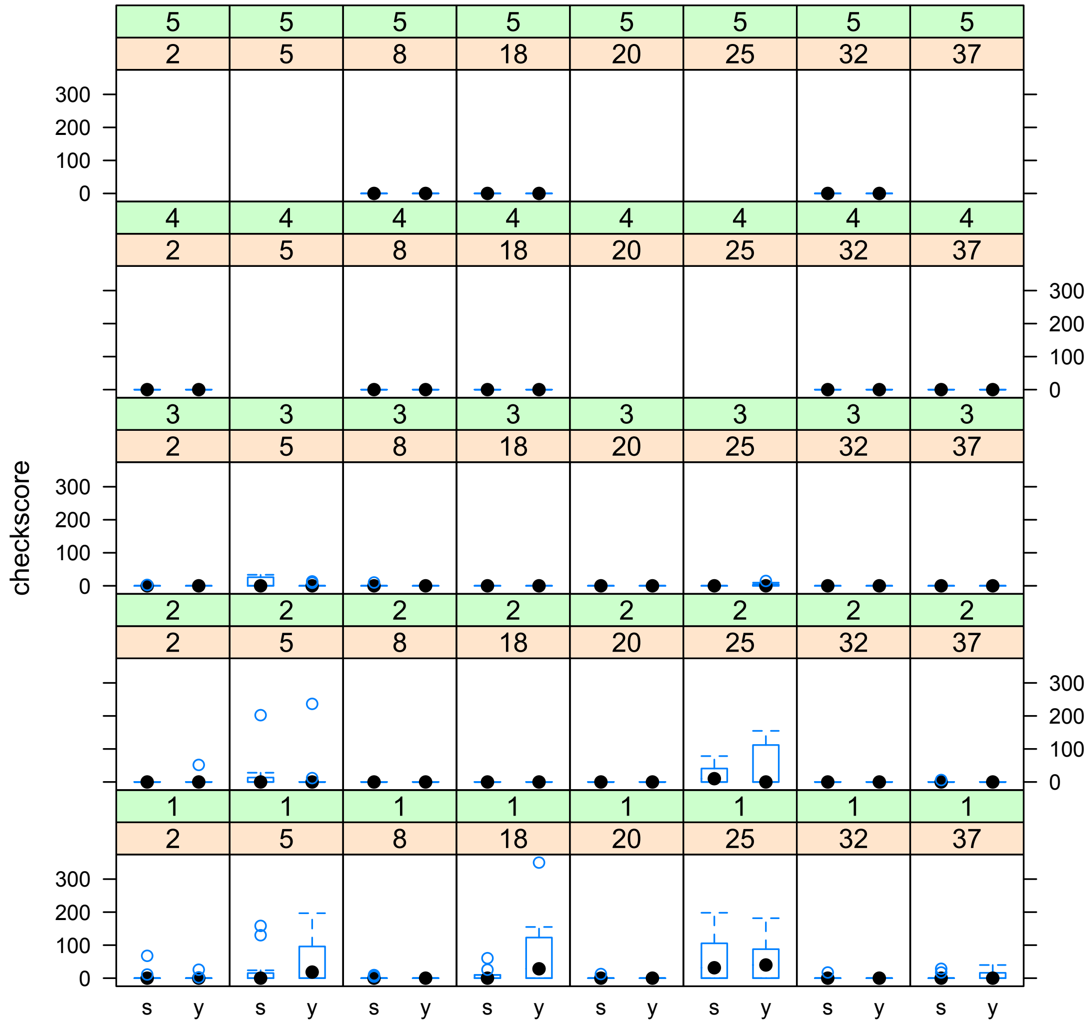

Figure 7. *Checking levels and standard deviations of checking levels as a score for trees and logs according to drying treatment (Y=yard drying, S=shed drying).*

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4.4 Price Estimates for Board Profiles

Prices per nominal cubic metre of graded timber were calculated for each product profile and are presented in Table 11 for the graded pairs survey method and Table 12 for the constant sum allocation method.

Table 11
Prices per Nominal Cubic Metre for Sawn Timber Profiles based on Graded-pairs Pricing Method

Length (mm)	Width (mm)	Price for Select / Clears grade	Price for Standard Grade	Price for Feature / High Feature Grade
> 1200	150	$1309.33	$1101.33	$917.33
> 1200	125	$1235.20	$1040.00	$864.00
> 1200	100	$1184.00	$996.00	$832.00
600 - 1200	150	$1194.67	$986.67	$802.67
600 - 1200	125	$1100.80	$902.40	$729.60
600 - 1200	100	$1016.00	$828.00	$660.00
300 - 600	150	$717.33	$552.00	$405.33
300 - 600	125	$595.20	$438.40	$300.80
300 - 600	100	$460.00	$308.00	$176.00

Table 12
Prices per Nominal Cubic Metre for Sawn Timber Profiles based on Constant-Sum Allocation Pricing Method

Length (mm)	Width (mm)	Price for Select / Clears Grade	Price for Standard Grade	Price for Feature / High Feature Grade
> 1200	150	$1333.33	$1205.33	$1072.00
> 1200	125	$1286.40	$1155.20	$1024.00
> 1200	100	$1216.00	$904.00	$956.00
600 - 1200	150	$1149.33	$1021.33	$888.00
600 - 1200	125	$1100.80	$972.80	$838.40
600 - 1200	100	$1032.00	$1088.00	$772.00
300 - 600	150	$1037.33	$906.67	$776.00
300 - 600	125	$988.80	$860.80	$908.00
300 - 600	100	$920.00	$792.00	$660.00

4.4.1 Price estimates for laminated panel feedstock

The narrow-width boards (50 mm and 75 mm wide) were priced as a residual value by estimating costs to produce a laminated panel product and subtracting these from the sale price of two laminated panels, each produced from the two board length categories. The results are presented in Table 13.

Table 13
Residual Product Values per Nominal Cubic Metre for 75 mm and 50 mm Width Product

Length (mm)	Width (mm)	Four Faces Clear	Two Faces / Edges Clear	One Edge Clear
300-1500	50	$1080.00	$1080.00	$1080.00
>1500	50	$1900.00	$1900.00	$1900.00
300 - 1500	75	$1080.00	$1080.00	$1080.00
> 1500	75	$1900.00	$1900.00	$1900.00

4.5 Log Pricing Models and Residual Values

Cost and revenue estimates were produced for each plot log from predictive models based on sample log data.

4.5.1 Sawn timber revenues

Revenues at the log level were calculated as the sum of board prices per log for each grading and pricing method. The sample log data showed no statistically significant differences below the 5% threshold between sawn timber revenue from the sample logs according to log SED (Table 14).

Table 14
Predicted Sawn Timber Revenue According to Log SED

Grading and Pricing Profile	Intercept	Slope	P Value
Farm Forestry Timbers Grading, Graded-Pairs Pricing	634.9333	-5.0587	0.0636
Farm Forestry Timbers Grading, Constant-Sum Allocation Pricing	661.8305	-5.2965	0.0505
Australian Standard Grading, Graded-Pairs Pricing	641.6792	-5.6025	0.0701
Australian Standard Grading, Constant-Sum Allocation Pricing	671.3272	-5.9709	0.0545

The relationship between sawn timber revenue and SED, averaged between grading and pricing profiles, is presented graphically in Figure 8 and ignoring collapse defect in Figure 9.

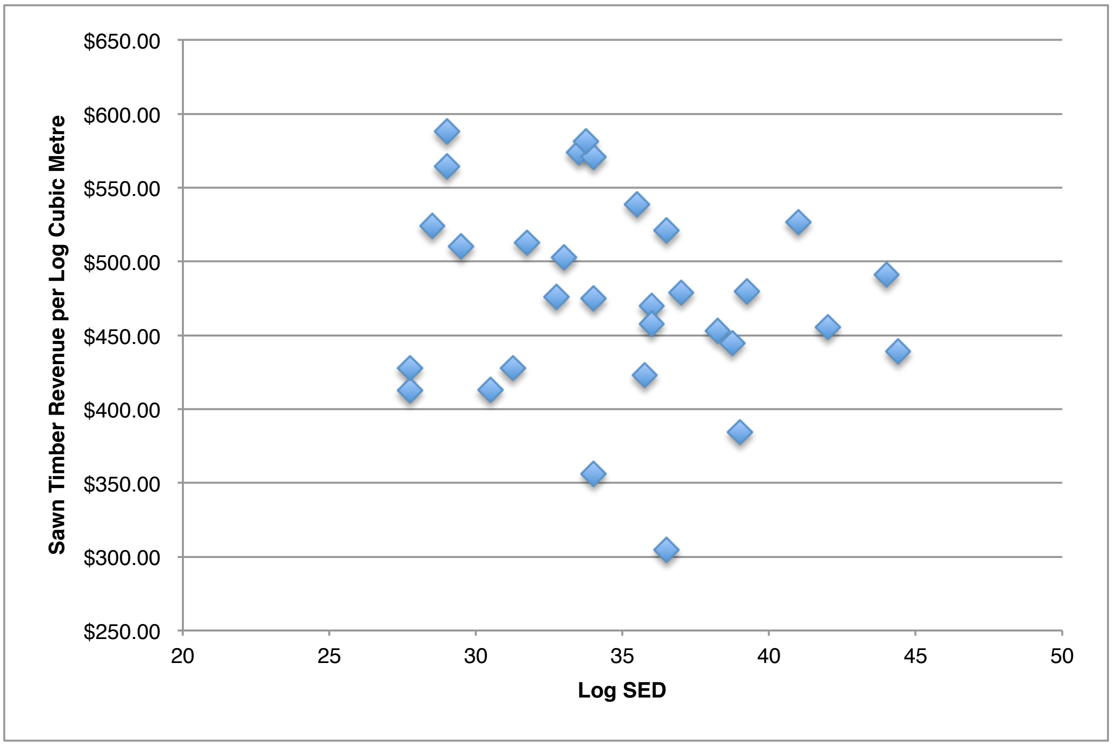

Figure 8. *Average sawn timber value according to SED.*

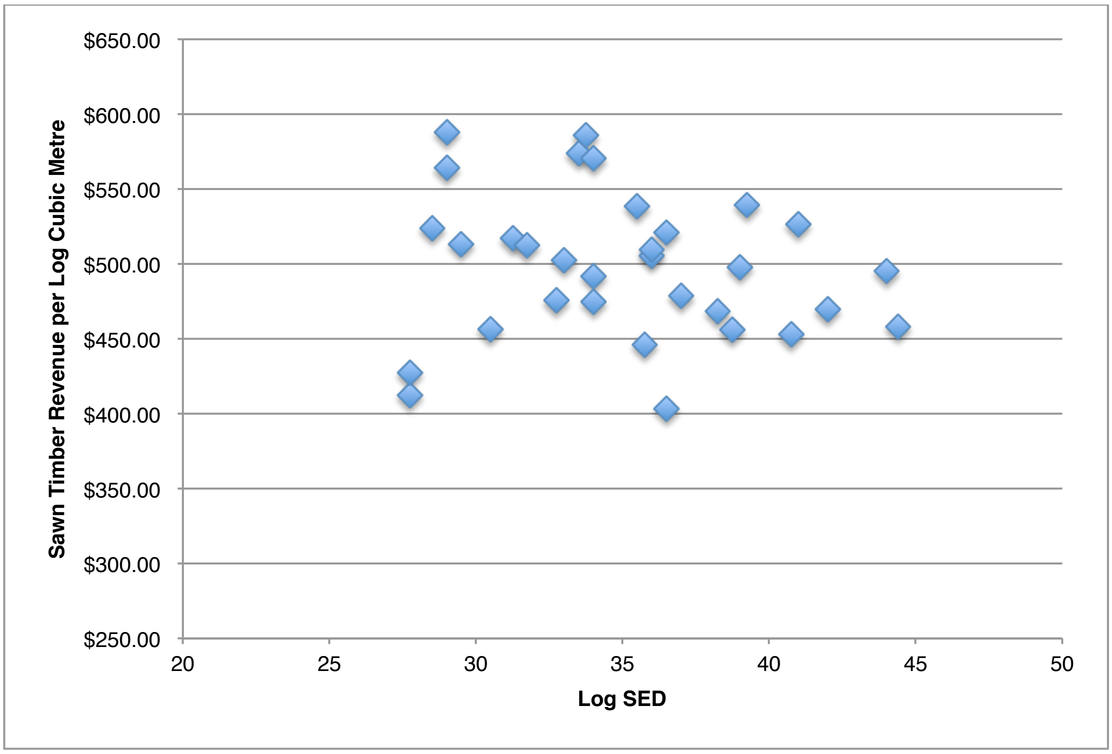

Figure 9. *Average sawn timber value per log cubic metre according to SED, Ignoring collapse defect.*

Differences according to log position were significant only between log 1 and logs 2-5.

Table 15
Mean Sawn Timber Revenue per Log Cubic Metre

Grading and Pricing Profile	Log 1	Logs 2-5	Average Revenue All Logs, Ignore Collapse
Farm Forestry Timbers Grading, Graded-Pairs Pricing	$465.78[1]	$504.31	$494.91
Farm Forestry Timbers Grading, Constant-Sum Allocation Pricing	$416.49[2]	$506.97	$520.10
Australian Standard Grading, Graded-Pairs Pricing	$376.96[3]	$480.07	$493.65
Australian Standard Grading, Constant-Sum Allocation Pricing	$391.89[4]	$497.84	$510.24

1. P= 0.014
2. P= 0.0134
3. P= 0.0132
4. P= 0.0106

There were no significant differences between all log positions under the scenario where collapse defect was ignored (i.e. assumed to have been reconditioned). Sawn timber revenue per log cubic metre (based on SED) for each scenario presented in Table 15 were used to model sawn timber revenue per hectare (Table 16).

Table 16
Sawn Timber Revenues per Hectare

Pricing and Grading Scenario	Farm Forestry Timbers Grading, Graded-Pairs Pricing	Farm Forestry Timbers Grading, Constant-Sum Allocation Pricing	Australian Standards Grading, Graded-Pairs Pricing	Australian Standards Grading, Constant-Sum Allocation Pricing
Not Reconditioned	\$216,361	\$225,114	\$210,511	\$218,452
Assumed Reconditioned	\$233,229	\$241,057	\$229,092	\$236,764

4.5.2 Marketing, management and processing overheads

Processing overhead cost at 10% of sawn timber revenue averaged \$21,760 per hectare between grading and pricing scenarios. This cost also represents sawmill profit in addition to return on capital investment.

4.5.3 Processing costs

Processing costs comprised sawmill costs (Figure 10), drying costs (Figure 11) and machining costs (Figure 12). Regressions for each processing cost contributing to residual value were found to be statistically significant per log cubic metre based on log SED. Second degree polynomial regressions were fitted for sawmill and drying costs whereas machining costs were fitted as linear.

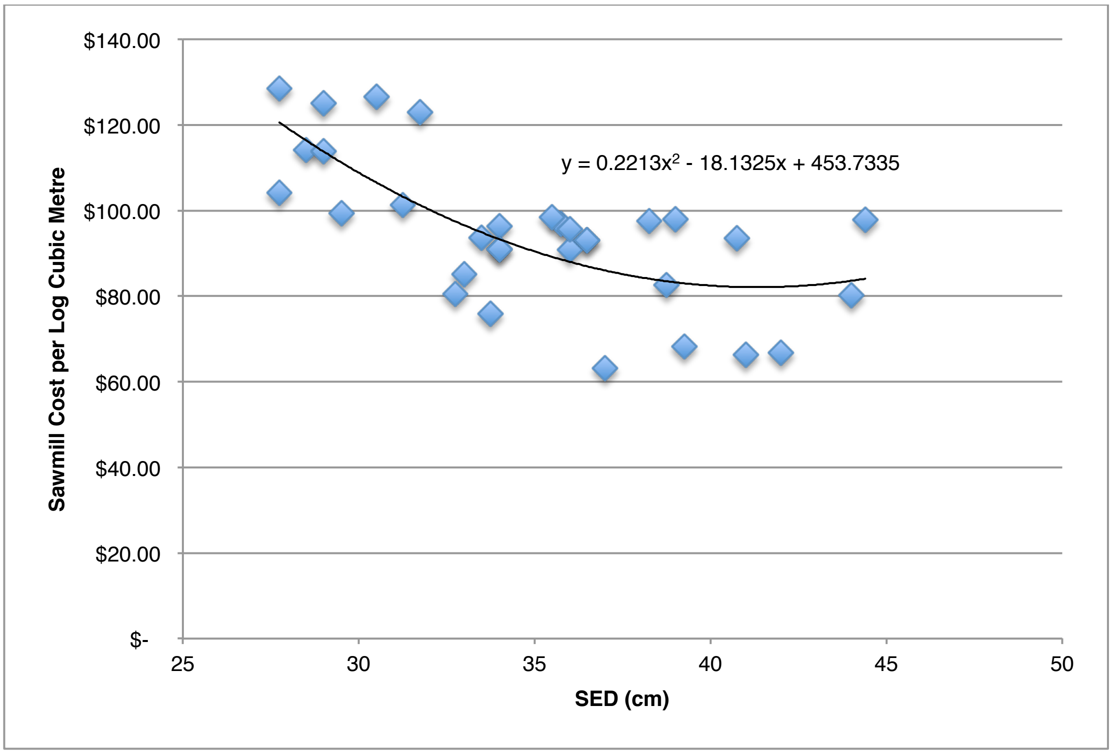

Figure 10. *Sawmilling costs per log cubic metre (P=0.0285).*

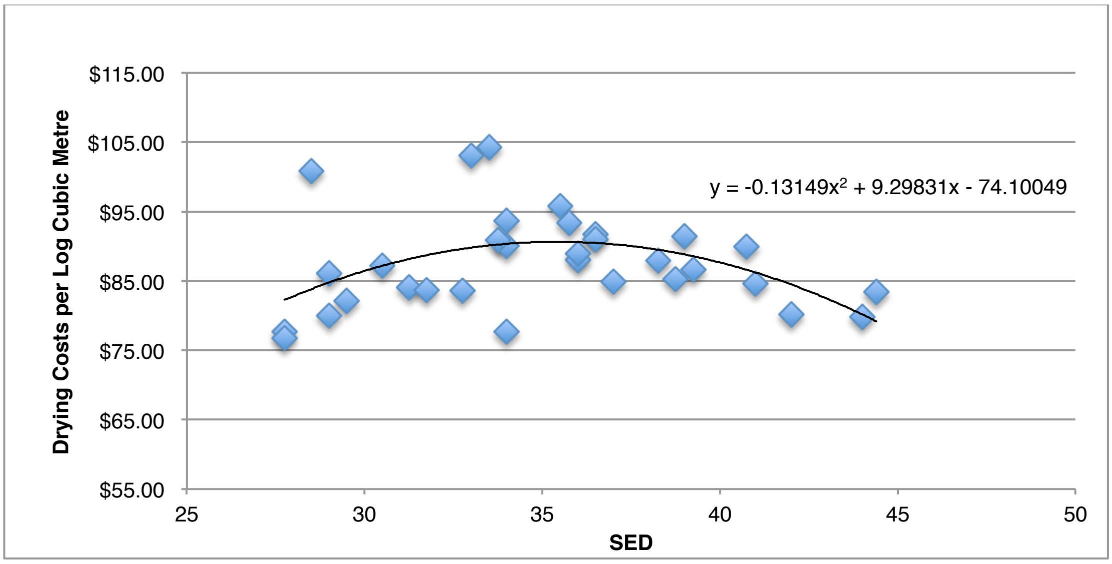

Figure 11. *Yard drying costs per log cubic metre (P=0.0095).*

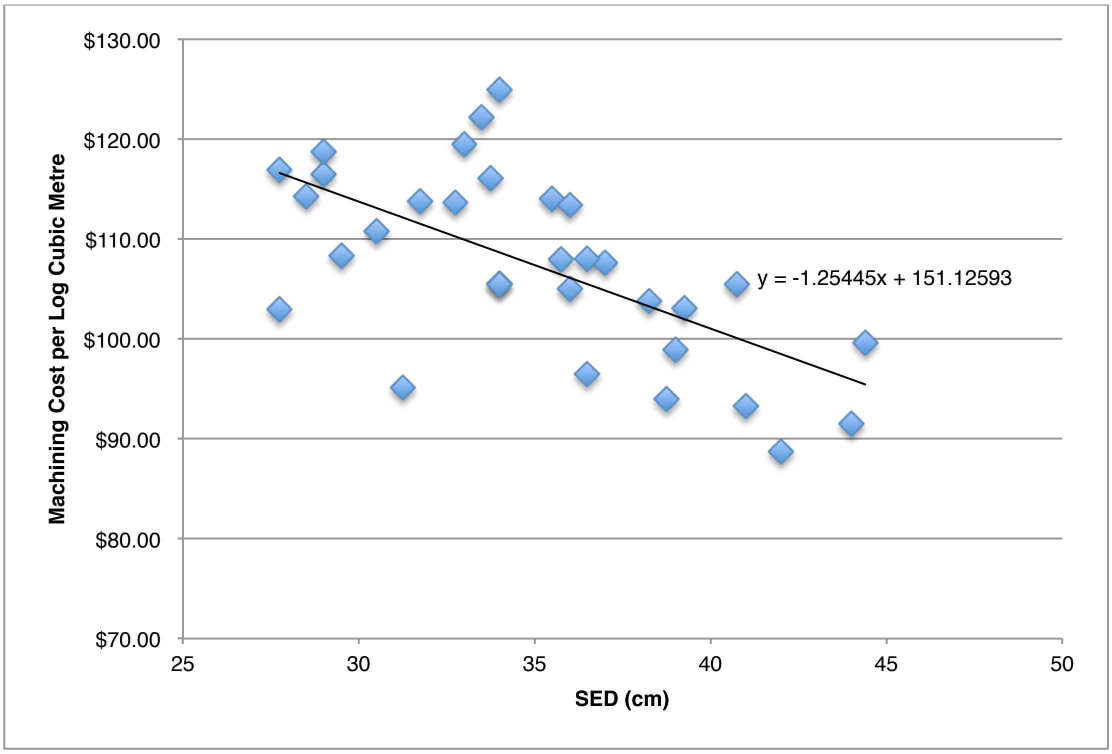

Figure 12. *Machining costs per log cubic metre (P=2e-04).*

4.5.4 Total processing costs

Summing processing overheads, sawmilling, drying and machining costs produced total processing costs per hectare, presented in Table 17.

Table 17
Total processing costs per hectare

Pricing and Grading Scenario	Farm Forestry Timbers Grading, Graded-Pairs Pricing	Farm Forestry Timbers Grading, Constant-Sum Allocation Pricing	Australian Standards Grading, Graded-Pairs Pricing	Australian Standards Grading, Constant-Sum Allocation Pricing
Not Reconditioned	$159,533	$160,408	$158,948	$159,742
Assumed Reconditioned	$167,213	$167,996	$166,799	$167,566

4.5.5 Residual values

Predicted residual values per log cubic metre for each combination of pricing and grading methods were estimated from predicted average sawn timber revenues per cubic metre for log 1 and logs 2-5, less predicted sawmilling costs, drying costs, processing costs and processing overheads per cubic metre. The residual value model was applied to plot logs and scaled to per hectare residual values. Total residual value per hectare was estimated for each pricing and grading scenario from sawn timber production not including secondary products and is presented in Table 18.

Table 18
Sawn Timber Residual Value per Hectare

Pricing and Grading Scenario	Farm Forestry Timbers Grading, Graded-Pairs Pricing	Farm Forestry Timbers Grading, Constant-Sum Allocation Pricing	Australian Standards Grading, Graded-Pairs Pricing	Australian Standards Grading, Constant-Sum Allocation Pricing
Not Reconditioned	$67,196	$75,074	$61,931	$69,078
Assumed Reconditioned	$76,384	$83,429	$72,661	$79,565

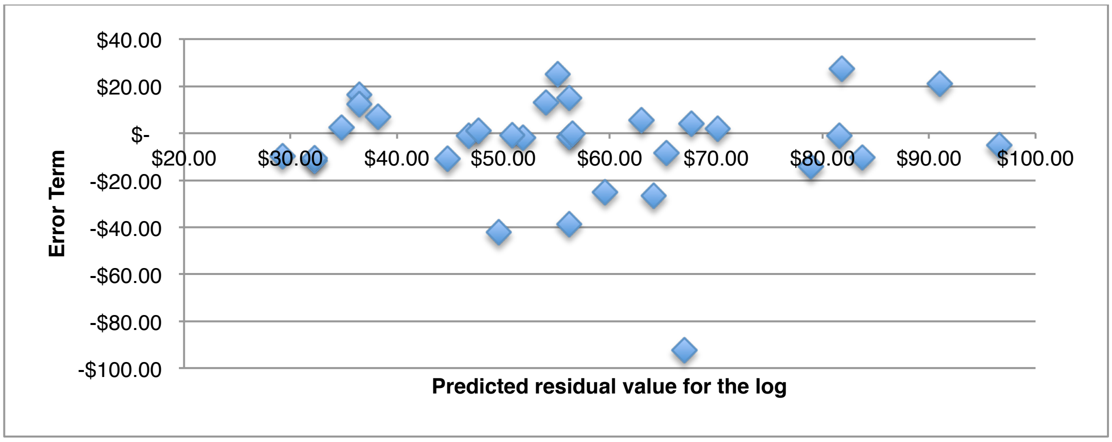

Figure 13. *Residuals, averaged between pricing and grading profiles.*

Average residual values from the sample logs that were processed were compared with average predicted residual log values for the sample logs. Figure 13 plots statistical residuals (error term) against the observed residual values for logs.

By ignoring collapse defect and adding the cost of steam reconditioning, log residual value averaged across the grading and price scenarios results in residuals presented in Figure 14.

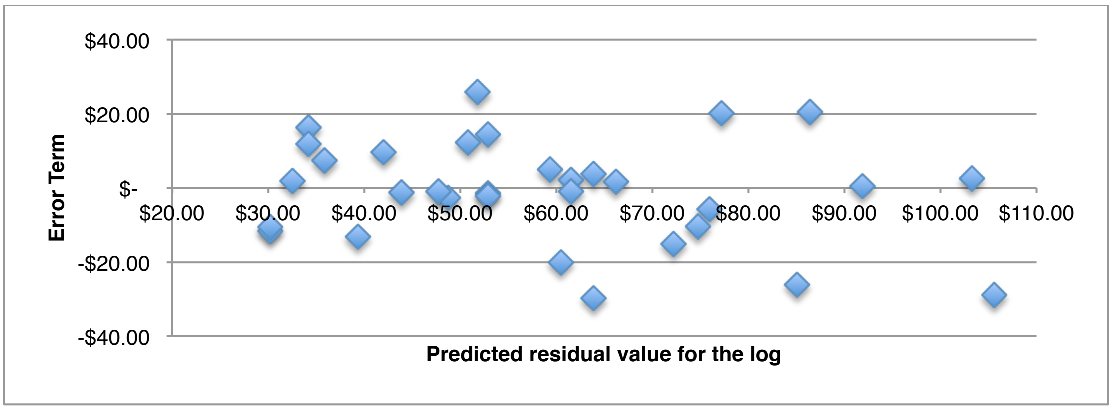

Figure 14. *Residuals, averaged between pricing and grading profiles*.

Revenue from secondary products is presented in Table 19.

Table 19.
Revenue per hectare from Secondary Products

Year	Pulpwood	Slab firewood	Sawdust
15	$993	--	--
16	--	$17,950	$5,541

4.5.6 Discounted cash flows

Based on a 15-year rotation and a discount rate of 8.5%, residual values per hectare for each pricing and grading scenario are presented in Table 20.

Table 20

Sawn Timber Residual Value per Hectare at Year 0

Pricing and Grading Scenario	Farm Forestry Timbers Grading, Graded-Pairs Pricing	Farm Forestry Timbers Grading, Constant-Sum Allocation Pricing	Australian Standards Grading, Graded-Pairs Pricing	Australian Standards Grading, Constant-Sum Allocation Pricing
Not Reconditioned	$18,217	$20,352	$16,789	$18,727
Assumed Reconditioned	$20,707	$22,617	$19,698	$21,570

Revenue from secondary products (pulpwood, slab firewood and sawdust) are presented in Table 21, as cash flows discounted to year 0.

Table 21

Cash Flows per Hectare From Secondary Products, Discounted to Year 0

Pulpwood	Slab firewood	Sawdust
$292	$4,866	$1,502

Growing costs and harvest/transport costs per hectare, discounted to year 0, are presented in Table 22, along with gross payments totalled to year 15.

Table 22

Growing Costs per Hectare, Discounted to Year 0

Year	Operational Growing Cost	Annual Growing Cost	Land Rental Growing Cost	Logging, Loading and Transport
0	$2,283	$4,417	$6,376	$10,876
15	$3,479	$4,028	$7,059	$36,976

4.5.7 Net present value

Based on a 15-year rotation and a discount rate of 8.5%, net present value per hectare for each pricing and grading scenario is presented in Table 23.

Table 23
Net Present Value per Hectare at Year 0

Pricing and Grading Scenario	Farm Forestry Timbers Grading, Graded-Pairs Pricing	Farm Forestry Timbers Grading, Constant-Sum Allocation Pricing	Australian Standards Grading, Graded-Pairs Pricing	Australian Standards Grading, Constant-Sum Allocation Pricing
Not Reconditioned	-$564	$1,571	-$1,992	-$54
Assumed Reconditioned	$1,926	$3,836	$917	$2,789

4.6 Sensitivity Analysis

Changes in net present values according to pricing scenarios, grading scenarios and when allowing for assumed improvements in drying degrade from steam reconditioning together provide data for a sensitivity analysis (Table 23) of methods. Other factors that most influence profitability include land price along with logging and transport costs. This section considers the impact land price, pulpwood price and logging and transport costs each have on productivity.

4.6.1 Land price

The base scenario assumes a land price of $10,000 per hectare, which is lower than actual land values in rural Rangiora, but very high for forestry land. Assuming productivity would not vary with land price, the influence of alternative land prices are presented in Table 24 and Table 25.

Table 24
Net Present Value per Hectare at Year 0 with Land Price of $20,000 per Hectare

Pricing and Grading Scenario	Farm Forestry Timbers Grading, Graded-Pairs Pricing	Farm Forestry Timbers Grading, Constant-Sum Allocation Pricing	Australian Standards Grading, Graded-Pairs Pricing	Australian Standards Grading, Constant-Sum Allocation Pricing
Not Reconditioned	-$7,623	-$5,487	-$9,050	-$7,113
Assumed Reconditioned	-$5,132	-$3,222	-$6,142	-$4,270

Table 25
Net Present Value per Hectare at Year 0 with Land Price of $5,000 per Hectare

Pricing and Grading Scenario	Farm Forestry Timbers Grading, Graded-Pairs Pricing	Farm Forestry Timbers Grading, Constant-Sum Allocation Pricing	Australian Standards Grading, Graded-Pairs Pricing	Australian Standards Grading, Constant-Sum Allocation Pricing
Not Reconditioned	$2,965	$5,100	$1,538	$3,475
Assumed Reconditioned	$5,456	$7,366	$4,446	$6,318

4.6.2 Pulpwood price

Canterbury does not have a market for hardwood chipwood, in contrast to the central North Island and Southland. Firewood log price in Canterbury of $50 per tonne delivered (See Appendix A2) or stumpage of $6 per tonne was used for the base net present values (Table 23) for logs between 10 cm and 25 cm diameter, but this is lower than average chipwood prices landed at mill in Southland of $75 per tonne (see Appendix A2). For the purposes of a sensitivity analysis, net present values are presented in Table 26 using an estimate of $75 per tonne delivered.

Table 26
Net Present Value per Hectare at Year 0 with Pulpwood Stumpage of $31 per Tonne

Pricing and Grading Scenario	Farm Forestry Timbers Grading, Graded-Pairs Pricing	Farm Forestry Timbers Grading, Constant-Sum Allocation Pricing	Australian Standards Grading, Graded-Pairs Pricing	Australian Standards Grading, Constant-Sum Allocation Pricing
Not Reconditioned	$2,058	$4,193	$630	$2,568
Assumed Reconditioned	$4,548	$6,458	$3,539	$5,411

A further scenario is presented in Table 27 where delivered price for 10-25 cm diameter logs of $44 equals the cost of logging and transport for a stumpage of $0.

Table 27 *Net Present Value per Hectare at Year 0 with Pulpwood Stumpage of $0 per Tonne*

Pricing and Grading Scenario	Farm Forestry Timbers Grading, Graded-Pairs Pricing	Farm Forestry Timbers Grading, Constant-Sum Allocation Pricing	Australian Standards Grading, Graded-Pairs Pricing	Australian Standards Grading, Constant-Sum Allocation Pricing
Not Reconditioned	-$1,194	$942	-$2,621	-$684
Assumed Reconditioned	$1,279	$3,207	$288	$2,159

4.6.3 Logging and transport

The base scenario assumes easy terrain with logging and loading costs of $28 per tonne plus transport costs of $16 per tonne for 50 km transport distance. An alternative scenario is presented in Table 28 with easy hill country logging cost of $31 per tonne and transport costs of $27 per tonne for 100 km distance. This resulted in a loss of $8 per tonne for the pulpwood logs. Another alternative scenario with moderate-steep country logging cost of $38 per tonne and $39 for 150 km transport distance is presented in Table 29. This resulted in a loss of $27 per tonne for pulpwood logs.

Table 28
Net Present Value per Hectare assuming Logging and Transport Costs of $58 per Tonne

Pricing and Grading Scenario	Farm Forestry Timbers Grading, Graded-Pairs Pricing	Farm Forestry Timbers Grading, Constant-Sum Allocation Pricing	Australian Standards Grading, Graded-Pairs Pricing	Australian Standards Grading, Constant-Sum Allocation Pricing
Not Reconditioned	-$4,706	-$2,571	-$6,134	-$4,196
Assumed Reconditioned	-$2,216	-$306	-$3,255	-$1,353

Table 29
Net Present Value per Hectare assuming Logging and Transport Costs of $77 per Tonne

Pricing and Grading Scenario	Farm Forestry Timbers Grading, Graded-Pairs Pricing	Farm Forestry Timbers Grading, Constant-Sum Allocation Pricing	Australian Standards Grading, Graded-Pairs Pricing	Australian Standards Grading, Constant-Sum Allocation Pricing
Not Reconditioned	-$10,327	-$8,192	-$11,755	-$9,817
Assumed Reconditioned	-$7,837	-$5,927	-$8,846	-$6,974

4.6.4 Sawn timber value

The influence price for sawn timber had on NPV was considered. The NPVs resulting from increasing revenue from sawn timber by 20% are presented in Table 30, and in Table 31 from decreasing revenue from sawn timber by 20%.

Table 30

Net Present Value per Hectare after Increasing Revenue from Sawn Timber by 20%

Pricing and Grading Scenario	Farm Forestry Timbers Grading, Graded-Pairs Pricing	Farm Forestry Timbers Grading, Constant-Sum Allocation Pricing	Australian Standards Grading, Graded-Pairs Pricing	Australian Standards Grading, Constant-Sum Allocation Pricing
Not Reconditioned	\$9,993	\$12,556	\$8,281	\$10,606
Assumed Reconditioned	\$13,307	\$15,599	\$12,096	\$14,342

Table 31

Net Present Values per Hectare after Decreasing Revenue from Sawn Timber by 20%

Pricing and Grading Scenario	Farm Forestry Timbers Grading, Graded-Pairs Pricing	Farm Forestry Timbers Grading, Constant-Sum Allocation Pricing	Australian Standards Grading, Graded-Pairs Pricing	Australian Standards Grading, Constant-Sum Allocation Pricing
Not reconditioned	-\$11,122	-\$9,414	-\$12,264	-\$10,714
Assumed Reconditioned	-\$9,455	-\$7,927	-\$10,262	-\$8,765

4.6.5 Drying degrade

Table 32

Net Present Values per Hectare After Removing Drying Defect

Reconditioning Scenario	Farm Forestry Timbers Grading, Graded-Pairs Pricing	Farm Forestry Timbers Grading, Constant-Sum Allocation Pricing	Australian Standards Grading, Graded-Pairs Pricing	Australian Standards Grading, Constant-Sum Allocation Pricing
Boards from all Logs Reconditioned	\$1,728	\$4,022	\$195	\$2,276
Boards from Logs 3-5 Reconditioned	\$2,377	\$4,671	\$844	\$2,925

Drying defect caused by collapse and checking present on profiled surfaces accounted for 7.42% of sawn timber production, averaged between grading methods. Accounting for the increased cost of stream reconditioning on drying costs for all logs and just logs 1 and 2, assuming this process improves revenue from sawn timber by 7.42%, resulting NPVs are presented in Table 32.

4.6.6 Sawmill Overheads

The base scenario includes a sawmill management and overhead cost of 10% of sawn timber revenue. Table 33 provides NPVs after altering this value to be either 5% or 15% of sawn timber revenue.

Table 33
Net Present Value per Hectare According to Sawmill Overheads

Sawmill Management Overhead	Farm Forestry Timbers Grading, Graded-Pairs Pricing	Farm Forestry Timbers Grading, Constant-Sum Allocation Pricing	Australian Standards Grading, Graded-Pairs Pricing	Australian Standards Grading, Constant-Sum Allocation Pricing
5% of Sawn timber Revenue	$2,368	$4,622	$862	$2,907
15% of Sawn Timber Revenue	-$3,497	-$1,480	-$4,845	-$3,015

4.7 Log Position as a Driver for Log Residual Value

Log physical characteristics varied according to log position in the tree and a number of relationships were evident. These are presented because of the potential for these to influence log residual value if sawn for solid timber.

4.7.1 Density and hardness

A single board sample collected from longitudinal mid-position from each log was tested for basic density. The relationship between density at test (average 11.77% moisture content) and log position is presented in Figure 15. Statistically significant differences were found between log 1 and logs 2 - 3 with a P value for log position of 0.013.

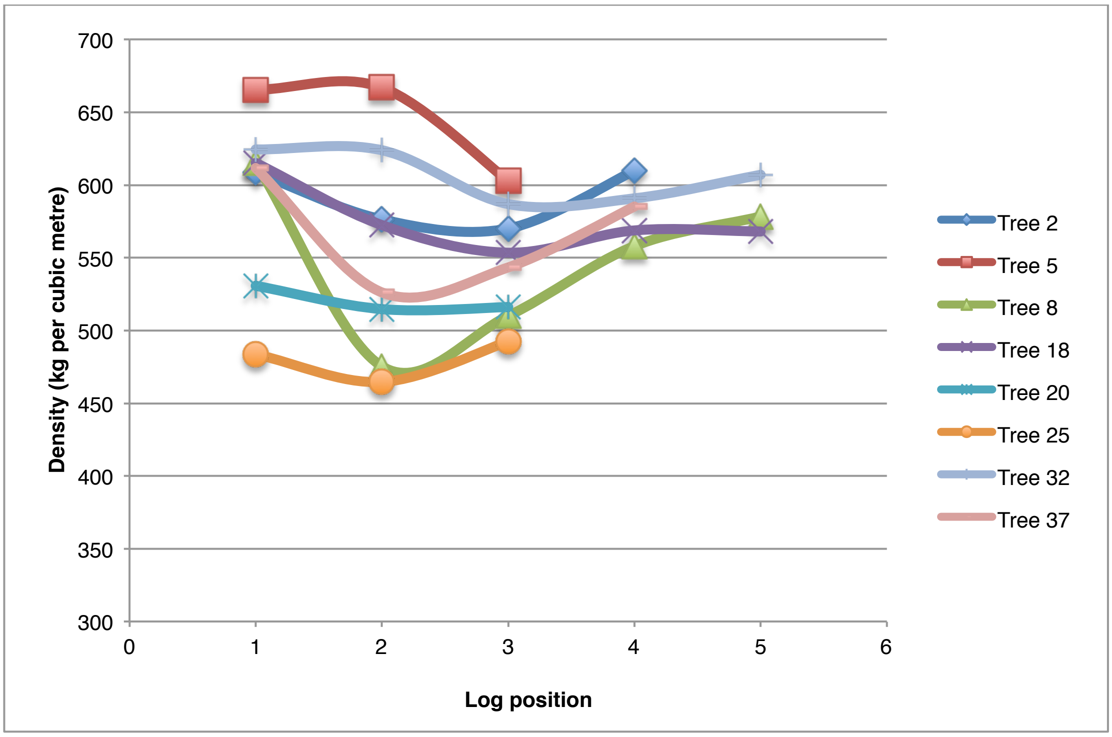

Figure 15. *Density at test according to log position from single sample tests.*

The test samples were also tested for hardness. The relationship between hardness and log position is presented in Figure 16. Statistically significant differences were found between log 1 and log 2 with a P value for log position of 0.0122, suggesting lowest hardness in boards from log 2.

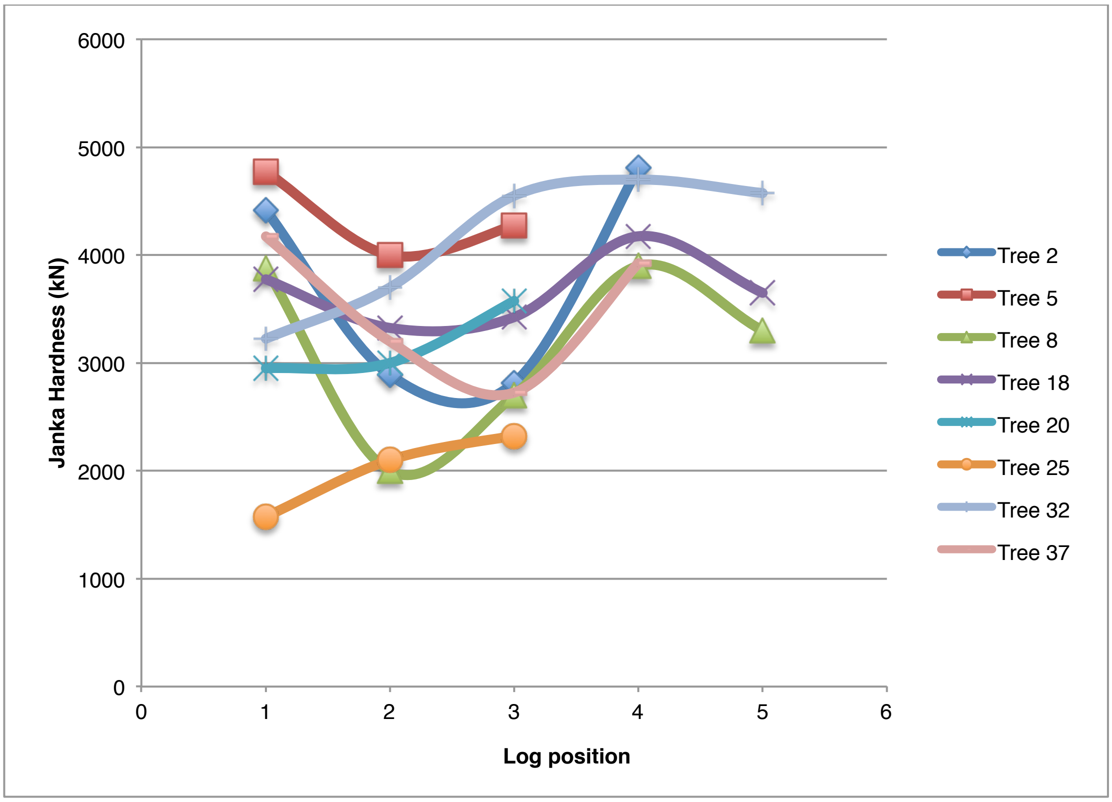

Figure 16. *Hardness according to log position from single sample tests.*

Log densities estimated from weighted and summed kiln-dried board weights are presented according to tree and log position in Figure 17. The trend is for boards from the second log to have the lowest density, with increasing density from the second log to the fifth log. The fifth log was significantly denser than log 1 ($P=0.0006$), whereas logs 2 ($P<0.0001$) and 3 ($P=0.0002$) were significantly lower density than log 1. No significant difference in density was evident between log 1 and log 4 ($P=0.7$).

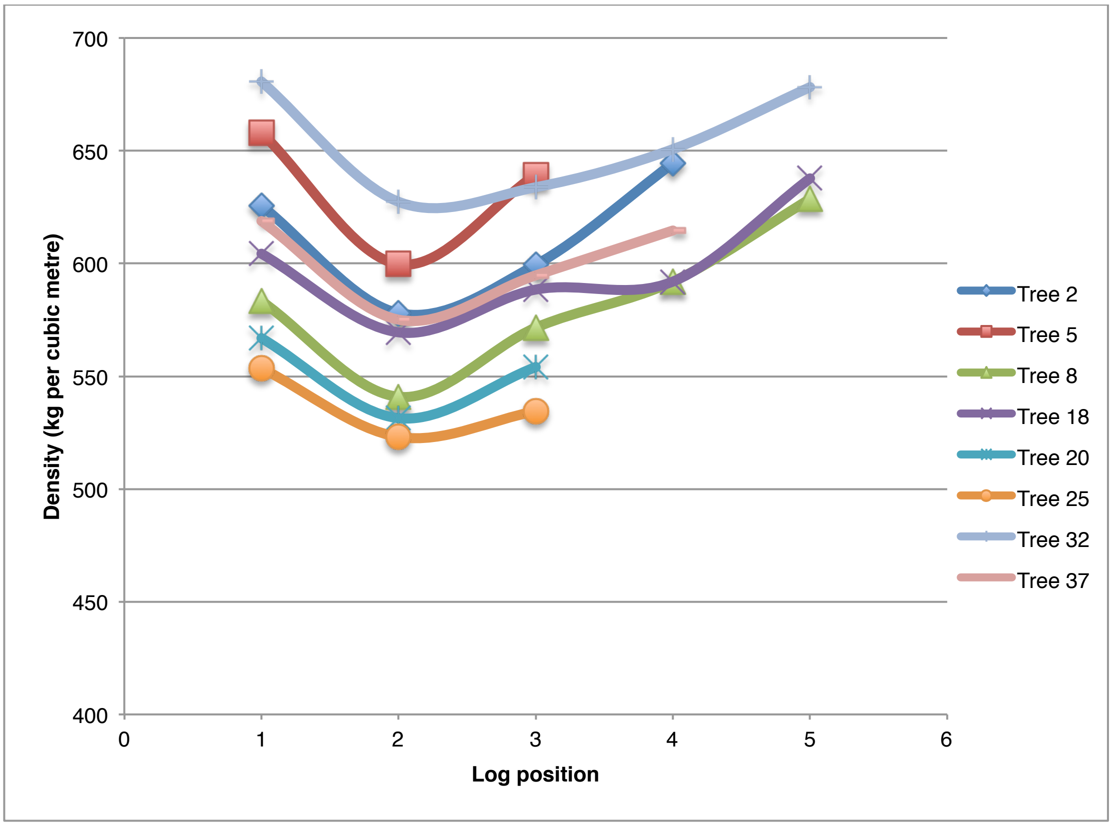

Figure 17. *Density for each log per cubic metre.*

Single sample hardness values correlate well with single sample density values (0.79) and individual log densities (0.74) suggesting that hardness is likely to follow the same trend as density.

4.7.2 Movement in service

Long-term movement in service was tested from the single board test samples from each log. The relationship between movement in service and log position is presented in Figure 18. The null hypothesis that there are no differences between movement in service in boards from log 1 and all other log positions can be rejected (P=0.0247), suggesting that movement in service is higher in log 1 than in log positions above this. There are no significant differences between log positions above log 1.

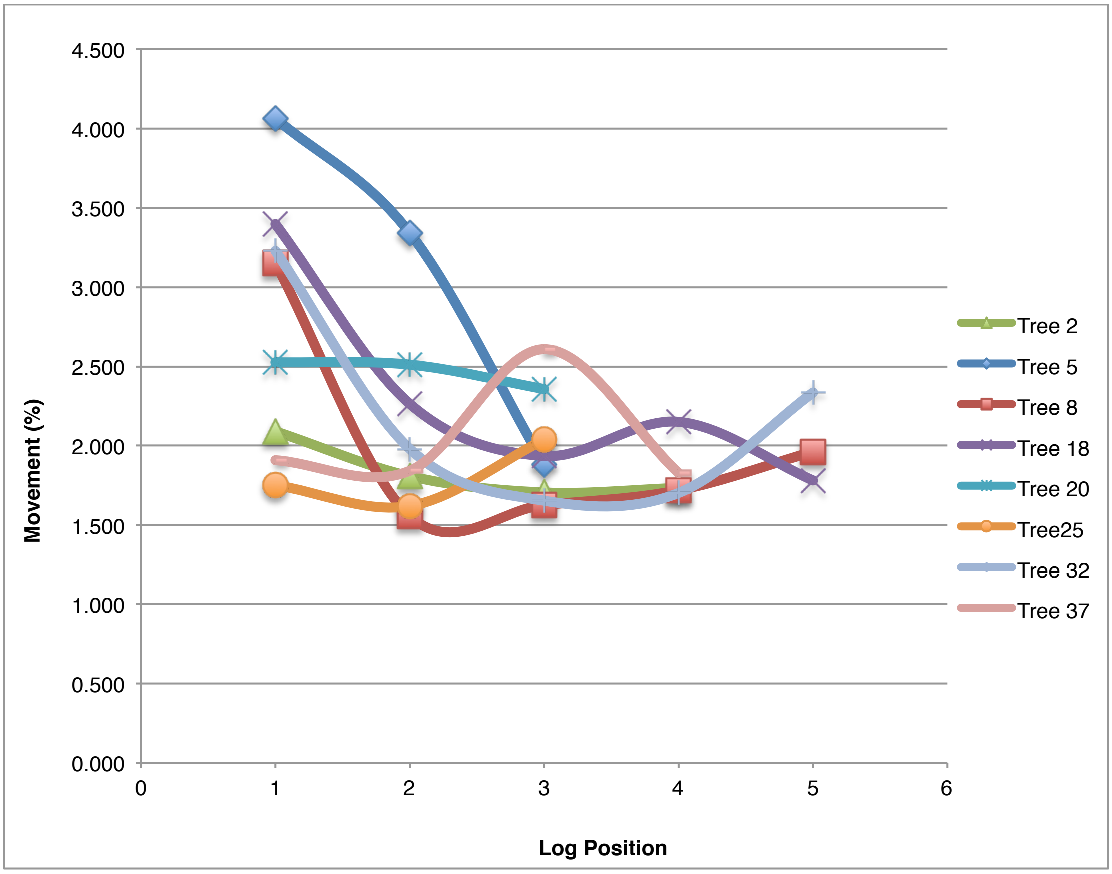

Figure 18. *Long term movement in service according to log position.*

Movement in service from single samples also held a strong relationship with density from the same samples (P=0.001). However, by removing log 1 from the dataset the relationship was no longer significant to the 5% level (P=0.0611), suggesting that as density increases with height in the tree, movement in service might not.

4.7.3 Defect and drying degrade

Log position was found to be important in determining levels of defect and drying degrade. Figure 19, Figure 20, Figure 21, Figure 22 and Figure 23 present percentages of defect levels from all sample boards according to log position.

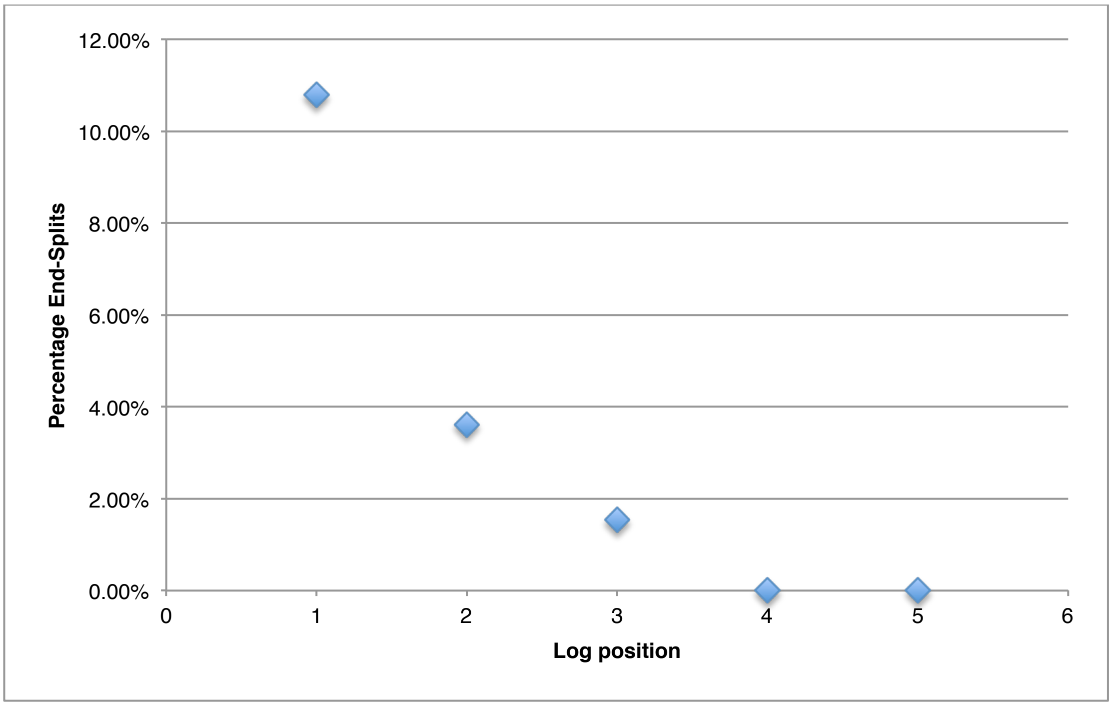

Figure 19. *Level of end-splits present in boards according to log position.*

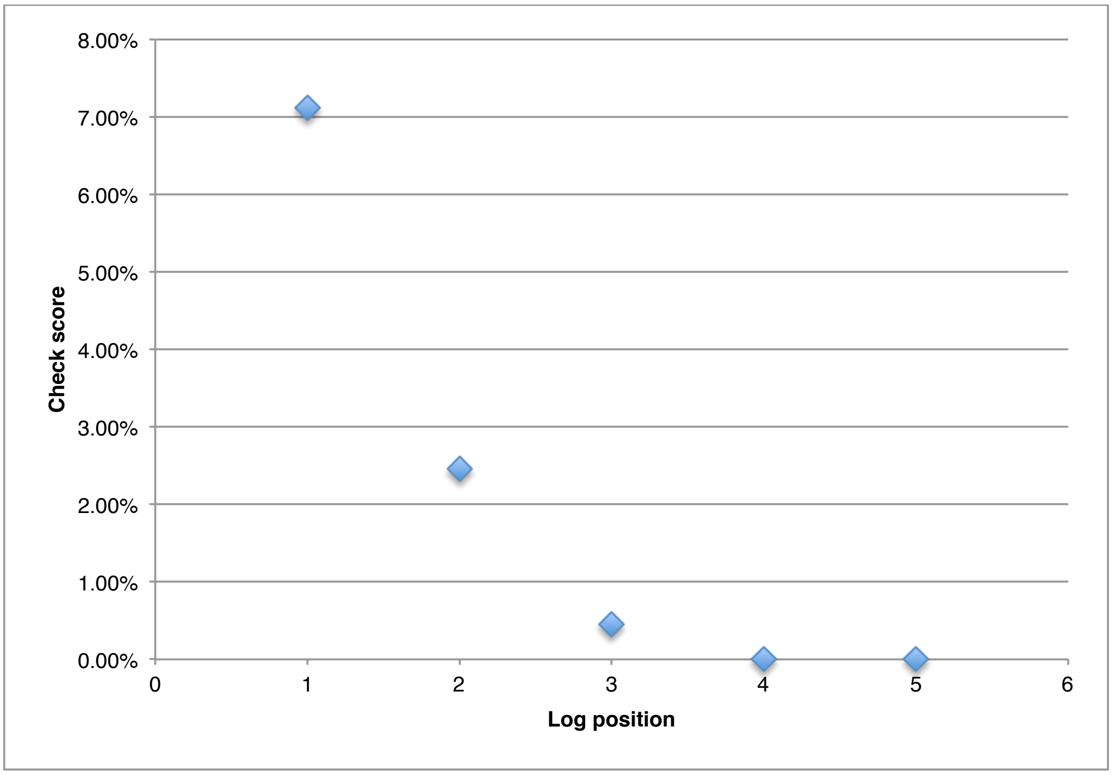

Figure 20. *Surface check levels on profiled product as a score.*

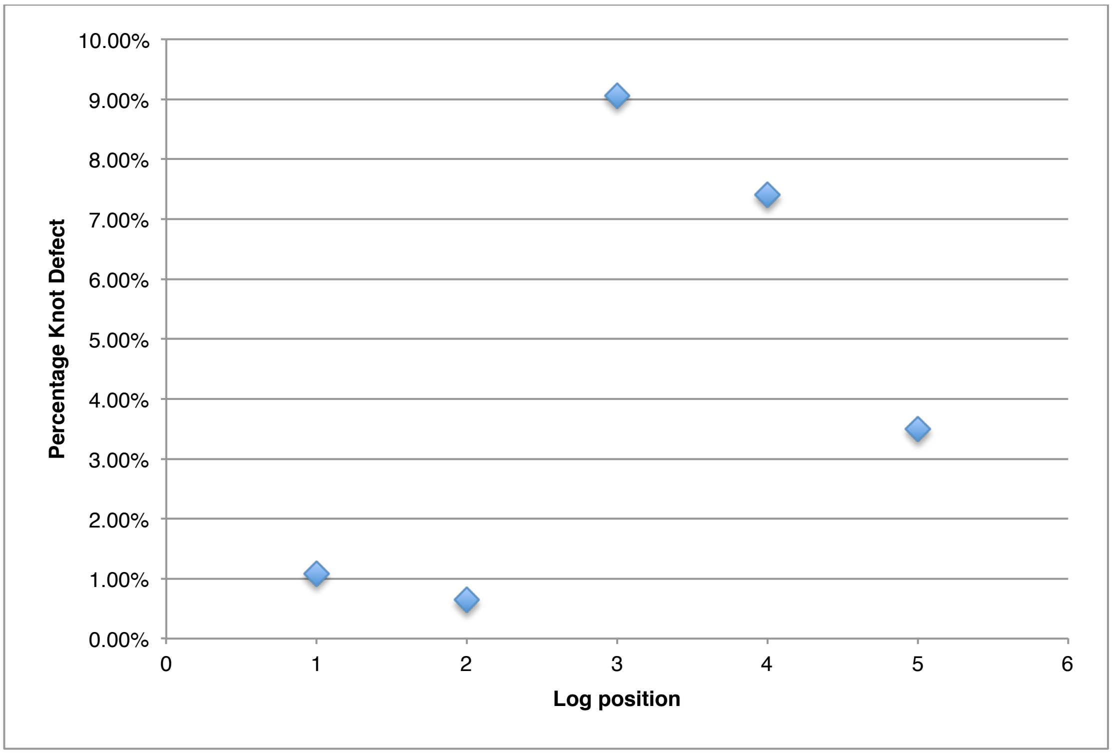

Figure 21. *Percentage of knot defect in all boards, graded to Australian Standards.*

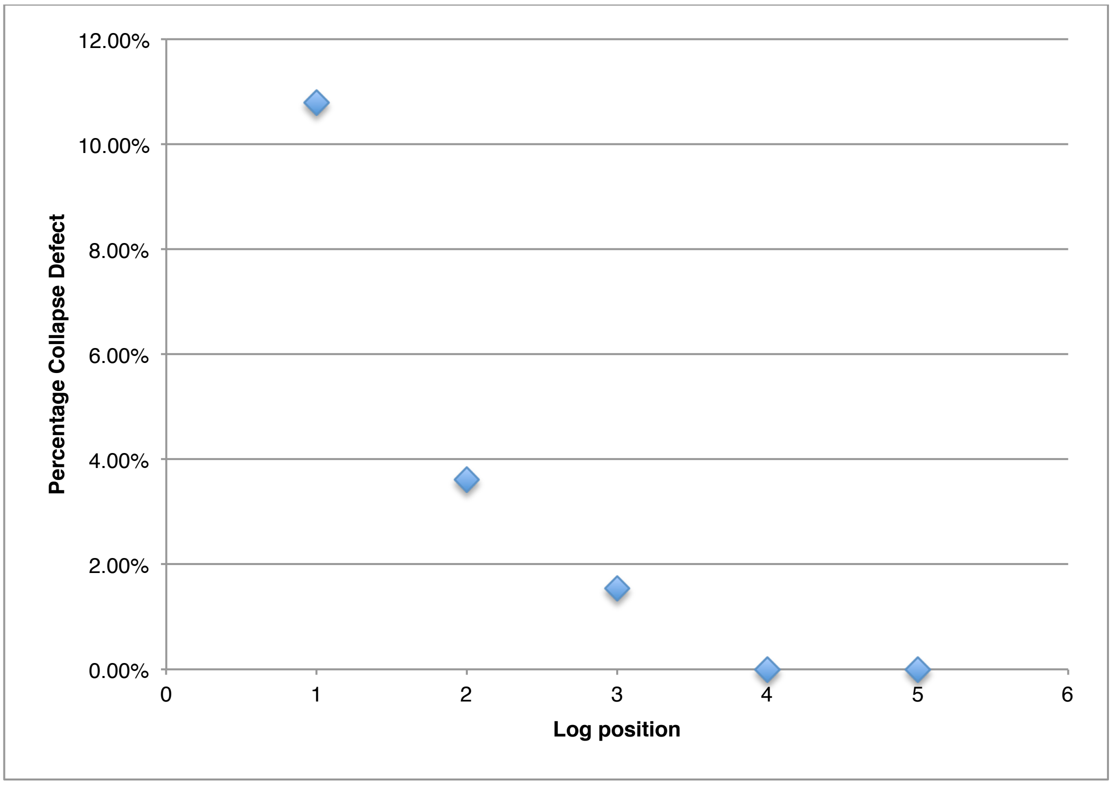

Figure 22. *Percentage of board volume as defect caused by collapse.*

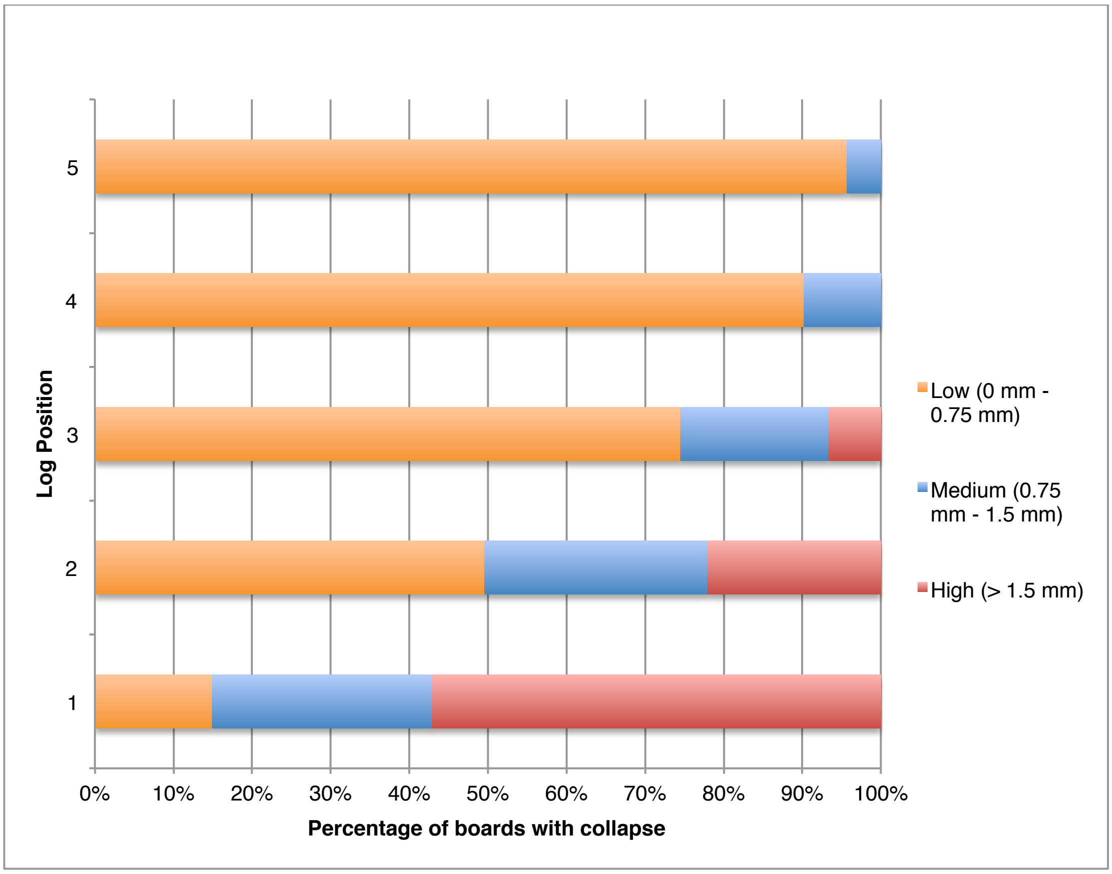

Figure 23. *Levels of collapse on un-reconditioned kiln-dried boards*.

Chapter 5

Discussion and Conclusions

5.1 Introduction

The research objective for this case study was to estimate profitability of growing *E. nitens* for solid timber products using the residual value method for pricing logs. The residual value method offers opportunities to appraise log values in the absence of market prices for the products being produced.

A range of issues emerged that influenced grade recoveries and price for sawn product. Both sawn timber value and production efficiency directly influence log residual value to the grower. The monetary value of sawn timber from each log is a key determinant for residual value to the grower, thus accurate pricing of products is required for investor confidence in the results. This also study attempted to produce an output efficiency benchmark based on best practice processing methods.

The discussion and conclusions chapter is divided into an analysis of results, then discussion of pricing issues and processing issues before a final conclusion.

5.2 Core Results

Core results are summarised in this section. These include sawn timber recoveries and values, drivers of profitability and a comparison of results with previous studies.

5.2.1 Sawn timber recoveries and values

Predicted nominal sawn timber volume produced per hectare was 221 cubic metres and average price for sawn timber was $985 per nominal sawn cubic metre.

This average price is lower than the wholesale price of NZ $1309 at 10 June 2014 for 125 mm long length select Victorian ash flooring product primarily because the quality was variable. Processing costs totalled $722.43 per nominal sawn cubic metre.

Averaged between the two grading and two pricing scenarios, estimated sawn timber value per hectare was $217,610 ($985 per nominal sawn cubic metre) and total processing costs $159,658 ($722 per nominal sawn cubic metre). After accounting for costs of production, average residual value from sawn timber was $68,320. Other products added $24,484 to revenue, primarily firewood ($17,950) as a by-product of the sawmill operation. Pulp logs (10 cm -25 cm SED) contributed only $993 per hectare from 24.1% of merchantable log volume from as estimated stumpage of $6 per cubic metre.

Average sawlog price as stumpage was $131 per log cubic metre. Average sawn timber value per log cubic metre was $419.

5.2.2 Drivers of profitability

Depending on the scenario, it is potentially profitable to grow *E. nitens* on a 15-year rotation for production of solid timber products on this fertile Canterbury case study site using the case study processing equipment. However, profitability is highly dependent on the scenario. The base scenario assumed a discount rate of 8.5%, a land price of $10,000 per hectare, $44 per tonne logging, loading and transport costs and a processing and management overhead cost of 10% of sawn timber value. Under this base scenario, assuming sawn timber was sold at year 16, average NPV estimate for the grower between the two pricing and two grading scenarios was -$260 per hectare.

Drivers that most influenced profitability for the grower in this case study included sawmill profit, price for sawn timber, land price, transport distance and implementing steam reconditioning as a strategy for overcoming collapse defect. These are addressed individually below:

1. **Land price:** High land prices in the locality of the case study stand are a result of lifestyle values and proximity to Christchurch city. The site is very productive with high *E. nitens* growth rates and is within 50 km of the case study sawmill. A land price of $5,000 per hectare produces a NPV of $3,269 per hectare, whereas a land price of $20,000 per hectare produces a NPV of -$7,318. Profitability would improve if equally productive sites were available with lower land prices that did not incur additional transport costs.
2. **Logging, loading and transport costs:** By reducing land value to $5,000 per hectare and increasing logging and loading costs from 'easy to flat' with 50 km transport costs ($44 per tonne, $36,976 per hectare) to 'moderate to steep' with 150 km transport costs ($77 per tonne, $64,708 per hectare), NPV reduced from $3,285 to -$6,494. In practical terms there is a trade-off between lower land price and higher harvesting/transport costs. Even with a nil land value NPV was -$2,964 under the high harvesting/transport cost scenario.
3. **Sawn timber revenue:** By increasing sawn timber revenue by 20%, NPV between the two pricing and two grading scenarios averaged $10,359. By decreasing sawn timber value by 20%, NPV between the two pricing and two grading scenarios averaged -$10,879. This range shows the importance of timber price to NPV. Improving the price estimates for *E. nitens* timber would require actual sales data or refined pricing techniques.
4. **Drying degrade:** Checking defect and collapse defect together accounted for 7.42 % of sawn timber production, averaged between grading methods. Checking degrade that was not sufficient to be categorised as defect, although

not quantified, resulted in further loss of value as drying degrade. Increasing average sawn timber value by 7.42% and including the additional cost of steam reconditioning for all boards improved average NPV to $2055. By only including the additional cost of steam reconditioning for boards from log one and log two, average NPV could be further improved to $2,705.

With steam reconditioning applied to all boards and assuming this process removed all collapse skip from profiled boards but did not remove checking defect, NPV improved to $2,367 per hectare. By applying the steam reconditioning process only to sawn timber originating from logs one and two (buttlogs), average NPV across grading and pricing scenarios increased to $3,017.

Further work on reducing drying degrade is justified given the significant influence this has on NPV. Selective tree breeding or improved drying methods are both strategies that could potentially provide meaningful improvements to profitability, along with more consistent quality of sawn product.

5. **Sawmill profit:** Lowering management and overhead cost for the processing operation from the base scenario to 5% of sawn timber value increased average NPV to $2,690. Increasing management and overhead cost for the processing operation from the base scenario to 15% of sawn timber value, NPV reduced to -$3,210. Further work on improved estimates of sawmill profit beyond return on investment is clearly justified given this has a significant influence on returns to the grower.
6. **Drying costs:** If drying costs not including steam reconditioning were halved from $202 to $101 per nominal sawn cubic metre, average NPV increased to $5,321 under the base scenario. Drying costs that include reconditioning for

ash eucalypt in Australia average $100 per nominal sawn cubic metre. Lowering timber processing costs from this base case study benchmark would improve growers' confidence in producing adequate returns.

7. **Grading:** The two grading methods produced an average difference in NPV of $1,526, from -$1023 for Australian Standards grading to $503 for Farm Forestry Timbers grading. By grading for specific products such as overlay flooring and flooring over joists, Farm Forestry Timbers grading improved estimated returns from sawn timber. This was achieved by allocating boards to end-uses rather than to general appearance grades. Features that are defective in general grades, for example large knots or other feature that causes structural weakness, do not limit application as overlay flooring where appearance is the primary driver of grade. The resulting improved log residual value reveals this advantage.
8. **Pricing survey methods:** The two survey methods used for pricing sawn flooring products produced an average difference in NPV between grading methods of $2,036, from -$1,278 for graded-pairs pricing to $758 for constant-sum pricing. Further work on pricing methods is justified and could potentially reconcile differences between these for improved pricing of timber products new to market.

5.2.3 Comparison with Previous Studies

Innes et al. (2008) and Washusen et al. (2008) reported estimates of residual value and revenue from solid timber production from plantation *E. nitens*. Comparisons with this study are presented in Table 34.

Table 34
Log residual value comparisons between studies

Study	Average sawn product revenue per hectare	Average sawn timber revenue per log cubic metre	Average mill door log value per cubic metre
Innes et al., 2008	A $106,434	A $233.33	A $72.37
Washusen et al., 2008	--	A $169	--
Case Study	$217,610	$418.68	$175.00

Although different sawmill, grading and pricing methods were employed in each study, with trees of different ages and under different silvicultural regimes, a significant improvement in sawn timber revenue and log stumpage is evident from this study (Table 34), suggesting that the processing methods employed resulted in improved grade recoveries from logs without incurring excessive costs. These included a focus on producing quality products that were straight and increasingly quartersawn as width increased, sawing 3 m log lengths and taking measures to reduce rate of air-drying of sawn timber.

However, the small scale of the case study processing operation and resulting high processing costs suggest there is room for improvement.

The dry board length rejected due to end-splits was relatively low (3.6%) considering that logs were cross cut to 3 m lengths. In comparison, Blakemore et al. (2010) reported 6.3% of the green board volume was rejected due to end splits from flatsawing 5 m log lengths. This emphasises the importance of sawmilling as soon as possible after cross cutting to minimise avoidable recovery loss.

Log size did not significantly influence log residual value in this study. This result is in contrast with previous studies claiming a price-size gradient such as Washusen et al. (2008, 2009). However, verifying these results would require a larger tree sample size to compare different log diameters each with the same log position to remove the interaction between log position and log size.

5.3 Study Design Issues

This study was implemented as a case study because it was not possible in a project of this magnitude to produce generalised findings on profitability of growing *E. nitens* for sawn timber production in New Zealand. This section focuses on shortfalls in application of methods, potential improvements to methods for future studies and design of methods that offer improved consistency.

5.3.1 Improvements to case study methods

Shortfalls in methods applied in this case study limited the accuracy with which the findings were supported by the evidence. Relationships and predictions are indicative rather than definitive because:

1. A larger log dataset would have been required to improve the accuracy with which sample sawlog data could predict sawn timber revenue, costs and log residual value according to diameter or log position.
2. Accurately predicting per hectare residual value would require improved inventory data such as random sample plots from a stand large enough to support rigorous population estimates.
3. If application of the sawmilling method were more accurate and consistent, this could potentially have reduced the variability in sawn timber recoveries

according to diameter and resulted in both higher sawn recoveries and more accurate sawn timber residual value predictions.

4. Sawlog sample size was not adequate throughout the full diameter range being sampled. This would be necessary to fit a more accurate model and reduce the possibility of not identifying a relationship where one exists.

5.3.2 Towards a standardised methodology

Methods for quantifying data applied in this study were designed for application in further research into profitability of plantation *E. nitens*. These include:

- Methods designed for unbiased scoring of checks that take into account both frequency and severity;
- grading of profiled timber surfaces to avoid measurement error;
- a logical grading defect prioritisation order that avoids confounding effects; and
- measuring check levels in unreconditioned timber to provide comparable, unbiased results.

By standardising methods used between studies, researchers would be able to validly compare study results and thus more efficiently progress research into improving product quality and profitability.

5.3.3 Sawn timber physical properties

Single sample testing for physical properties were not sufficient for defining these. Larger sample sizes for physical property tests would be required for identifying statistically significant relationships between log position and physical properties that influence value. However, indications from this study, with its limited budget and scope, do incentivise further work to deliver generalised results that define links between physical properties and profitability. Hardness, movement in service and density all showed trends according to log position. These characteristics are drivers of log value.

5.4 Factors influencing grade recoveries from logs

A range of factors influenced grade recoveries and costs in this case study.

These include sawmill efficiency, log position and log diameter along with levels of deflection, defect and degrade, associated with these, discussed in this section.

5.4.1 Sawmill efficiency

Percentage sawn recoveries from the log were optimised within a diameter range for the equipment used in this case study (Figure 4). Sawmill costs per log cubic metre (Figure 10) and per sawn cubic metre (Figure 5) were also optimised within a diameter range. Log diameters both above and below the optimum produced decreasing sawn recoveries and at a higher cost per sawn cubic metre of production. Polynomial regressions provided the best fit because costs and efficiencies were not linear. However, number of sample logs was insufficient at each end of the range sampled, leading to less certainty in the trends predicted from the top and bottom end of the diameter range.

When slabbing large log quarters, rather than cutting two of these simultaneously as was practiced on smaller diameter logs in this case study, the quarters were cut individually. This was observed to slow production, and in Figure 5 production efficiency drops off at the top end of the diameter range. Unfortunately because there were only two sample logs above 43cm diameter, there were insufficient data points to corroborate this result. It is also notable that in larger logs wastage can result from slabs that are too wide for production of 150 mm boards. Because the target nominal width was a maximum of 150 mm for a flooring product that maintains adequate stability in service, the edger operator must choose to saw either one 150 mm board from the wide slab, or two narrower-width boards with less wastage. This was observed to be an issue with slabs from logs at the large end of the diameter range. Larger logs appeared to slow throughput and reduce sawn recoveries.

The case study sawmill equipment efficiency could potentially be optimised for larger logs, but in the configuration applied in this case study operated optimally at approximately 33 cm - 43 cm SEDs in terms of sawmill costs per sawn cubic metre. The tree stocking of 480 stems per hectare was possibly higher than optimum for this equipment with average plot sawlog diameters of 32.94 cm. The implication is that growers could potentially target a log diameter range that matches production efficiency of the anticipated sawmill equipment to maximise profitability.

Potential improvements to sawmill efficiency were most evident with the twin blade edging equipment. A higher level of precision in edging would likely improve both the quality and quantity of recovered sawn timber. In this study, because the slab was presented to the rollers freestyle with no fence for guidance, operator error was inevitable, resulting in either skip or sawn recovery forgone. Laser guidance would offer visual cues for exact positioning of slabs on the edger infeed and would likely improve sawmill efficiency.

At times the bandsaw was observed to deviate from a straight face cut, leading to slabs with varying thickness. The operator should change bands at regular intervals to ensure that bands are sufficiently sharp for straight cuts before this happens (J. Fairweather, pers. comm.).

The first cut should be exactly through the pith to ensure sawn recoveries are optimised. In practice this does not always happen. Methods could be developed to facilitate fast and accurate placement of logs for receiving the first cut.

These issues if corrected could improve production efficiency but also improve consistency of recoveries and therefore reduce variation. Less variation in recoveries from sample logs would produce more accurate predictions for the population.

5.4.2 Log Position

Logs from higher positions in the tree produced lower levels of drying degrade in boards than logs from lower positions.

Some buttlogs performed very poorly with high levels of drying degrade. This could be a tree (phenotype) effect as observed by Shelbourne et al. (2002). In this study one tree in eight performed very poorly in terms of collapse and checking defect in the first two logs, while two trees performed moderately poorly and five trees performed relatively well. Only one log out of thirty-two performed very poorly and five logs out of thirty-two performed moderately poorly. However, a larger dataset would be required to more accurately quantify this 'ratio of performance' between trees in terms of processing performance. This could lead to more accurately predicting economic impact of drying degrade on log residual value per hectare and according to log position.

Tree breeding strategies to select for lower levels of collapse and checking, or alternatively improved processing strategies are both opportunities that could lift profitability to the grower for *E. nitens* trees destined for solid timber production.

Pruned buttlogs had low levels of defect caused by branches and produced comparatively longer board lengths of higher grades than unpruned headlogs. Best practice pruning methods were applied to these trees to minimise the knotty core (Patrick Milne, pers. comm.) and these methods are vindicated by the results.

Pruned buttlogs were estimated to be 60% of total sawlog volume in this study, so if the problems with collapse and checking in these logs could be overcome further by improved processing methods, residual value per hectare would likely improve significantly. Results from this study indicate that on average, value of buttlogs is lower than headlogs per log cubic metre, despite the lack of degrade caused by knots. Minimising drying degrade from logs 1 and 2 remains a challenge for researchers to overcome.

Average sawn timber value per log cubic metre was higher from headlogs than from buttlogs, despite unpruned headlogs having significantly higher levels of box defect caused by knots than pruned buttlogs. This is explained by decreasing collapse defect, checking defect, checking degrade and end-splits with increasing height in the tree.

End-splits accounted for 3.6% of nominal sawn timber volume despite sawmilling as soon as practicable after cross-cutting logs. Although a comparatively good result, end-splits remain an important issue impacting on profitability, especially for buttlog sawlogs.

Unpruned headlogs yielded acceptable recoveries of longer lengths of higher grades (over 50% of nominal sawn recoveries were >1.2 m length, clears/select or standard grades). The shorter-length flooring product (600 mm - 1200 mm) yielded a potentially marketable product and the shortest length clears (300 mm - 600 mm) were only 2% of the total volume of flooring product from headlogs. Taking into account that headlogs had so little degrade from checking and collapse defect, it was not surprising that despite the smaller log diameters, sawn timber revenues were not lower per cubic metre than for pruned buttlogs.

The tradeoff with improved log quality higher in the tree is inevitably smaller average log diameter. Further refining log price estimates based on both position in tree and diameter could improve the ability to predict optimum rotation length and tree stocking for greatest returns to the grower.

5.4.3 Log diameter

A price-size gradient, or relationship between SED and sawn timber revenue per log cubic metre was not quite statistically significant (0.06 averaged between grading and pricing methods) at the 5% threshold for the range of log diameters sampled (see Table 14). However, because the possibility of a type 2 error is high with the small tree sample size used in this study, it is possible that these relationships could be established as statistically significant with improved methods using the same processing equipment and log diameter range.

In this case study smaller diameter logs yielded larger volumes of narrower width material per sawn cubic metre of production. Board price per sawn cubic metre is generally known to increase with board width. However, SED was not a significant predictor of sawn timber revenue in the product range selected for this study. Although wider boards would be expected to command higher prices per cubic metre, the average price discount market survey respondents gave to 100 mm boards from 150 mm boards per square metre was only 10% (Satchell, 2015). Because high per cubic metre product residual values were estimated for narrow board widths as laminating stock for panels (see Table 13), in this study sawn timber prices did not vary significantly between board widths. These price estimates reflect the products chosen for sawing in this case study and the methods for pricing these products rather than findings that could be generalised to other operations with a different product range. A product range that produces higher prices as board widths increase might also produce a more significant price size gradient for logs.

If an industry were to emerge growing and processing *E. nitens*, once the log market reached equilibrium, because each sawmill has an optimum log diameter range within which operation efficiency is optimised, sawmills would target their preferred diameters and potentially pay a premium for logs in highest demand. The sawmill would also need to consider their own price size gradient as determined from the products they produce and market demand for these.

5.4.4 Half-log deflection

Deflection or 'movement off the saw' did not explain sawn timber recovery, nor sawn timber revenue. Neither log position nor SED explained deflection, nor did end-splits. By sawing 3 m log lengths combined with edging of slabs, the effects of deflection were either mitigated to the point that they were not significant, or alternatively there was a type 2 error for the relationships. A larger dataset would be necessary to confirm which is most likely.

Level of deflection did almost explain levels of end splits in dry boards ($P=0.076$). This relationship deserves more attention because if growth strain could be mitigated through selective breeding, end-splits could potentially be reduced simultaneously.

5.4.5 Crook

Because straightening cuts were applied to green slabs using a twin-blade edger, crook in the green sawn boards was not measurable. However, some boards were observed to develop crook during drying. Rather than measure levels of crook in dry boards it was decided to measure the consequences of crook in dry boards in terms of overall product value. Because one key quality criterion for the flooring product was production of perfectly straight profiled boards with nil crook, a straightening edge was employed when dressing the boards. Because level of crook increases with board length, full-length boards with crook present above an arbitrary threshold were docked so that shorter lengths were presented to the machine for straightening. This ensured that excessive skip did not result from straightening boards. The consequence of this strategy was that average board length was reduced. Some skip did also result from straightening as a result of judgement calls on appropriate lengths to be straightened. Although the specific loss of value caused by crook from drying was not measured, the consequences were a loss in value of sawn timber.

5.4.6 End splits

The strategy employed in this study was designed to minimise losses in sawn timber recoveries caused by end splits. Loss of value caused by end splits in short log lengths needs to be weighed against the gain in sawn timber recoveries resulting from straightening cuts over short log lengths. In practice this tradeoff resulted in selecting 3 m log lengths for all sample log diameters. The relatively low levels of board defect caused by end splits (3.6% of nominal sawn timber volume) highlights the strength of a strategy utilising short log lengths sawn as soon as possible after cross cutting.

5.4.7 Box

The primary cause of box defect in case study logs was the presence of defective knots in the sawn timber. Box defect is unavoidable, but by quantifying levels of knot defect in unpruned headlogs according to log position or diameter, opportunities could emerge that offer insight into improved silvicultural practices or highest value products for the diameter or position of the log. Consumers value appearance products free of knots and discolouration, but board length between knot defects must also be sufficient to meet the needs of the market for target products. Although the quantities of box defect were relatively low on average in headlogs and the lengths of graded pieces were adequate for flooring applications, of interest for valuing logs is the high levels of knot defect observed in the first unpruned log compared with those above it. If this finding were generalised it could become a factor influencing log value. This case study clearly justifies further work on quantifying levels of knot defect and board grades and lengths in unpruned logs according to log position and diameter.

A range of factors could be responsible for influencing levels of box defect, including silviculture, species, site and sawmilling method. Indications from this study are that further research is well justified into the economic potential of unpruned *E. nitens* headlogs for solid timber appearance applications, with some clues evident for developing strategies to match log properties from headlogs with products that could yield greatest residual value. Effect of tree stocking on levels of box defect both before and after thinning deserves attention.

5.4.8 Drying Degrade

Methods for controlling rate of air drying are not well published in the literature. Such methods would require weighing of costs against benefits before any one solution could be offered as having commercial benefits. For example slowing the rate of drying from standard practice offers the opportunity for improved drying performance only if it were evident the benefits outweighed the costs.

This study compared two methods of air drying. Air drying outdoors, provided stacks are suitably weighted, positioned and wrapped to reduce air flow, appears to be a more cost-effective method for drying *E. nitens* sawn timber than air-drying in a drying shed. This is because costs are lower and no significant differences in resulting sawn timber product values were evident between these methods.

Once air dried, *E. nitens* timber is required to be 'finished' in a kiln to bring the moisture content down to levels suitable for a marketable product. Costs for kiln drying are very dependent on scale. Kiln drying costs were high in this study and managing drying costs at competitive levels could be an issue for small-scale processors.

Steam reconditioning is routine practice in Australia, an indispensable part of the process of drying collapse-prone eucalypt timber. The opportunity cost of not steam reconditioning is the loss in value of the timber in excess of the savings from not subjecting the timber to the reconditioning process. Overall profitability was improved by steam reconditioning boards from all logs at a green sawn board thickness of 28 mm. However, for logs in positions higher in the tree, steam reconditioning appears to not be necessary and the price of these logs could reflect the consequential reduction in processing costs.

5.5 Product Selection and Pricing

Pricing of sawn products for this case study involved inferring product residual values along with application of direct pricing techniques as results from a market survey. These methods were necessary for estimating market prices empirically for *E. nitens* sawn timber products because these are not currently available in the market. The key issues identified from this study relevant to maximising value include appropriate selection of products and appropriate methods to produce products acceptable to market. These are outlined below.

5.5.1 Grading methods and end uses

Appearance grade rules as found in New Zealand and Australian grading standards apply general quality classes to all appearance end uses. A shift from general appearance grades to those based on specific end-uses could lead to greater market acceptance of degrade or feature not of importance to the end-use. By allowing feature in overlay flooring that meets general rules for appearance but is not compliant with general structural rules necessary for flooring over joists, Farm Forestry Timbers grading methods improved sawn timber value from Australian standards grading methods. The challenge for market development of plantation hardwood products could indeed be in shifting the market demand from general grade expectations as held in traditional markets dominated by old growth hardwood timber, towards acceptance of products produced for specific applications that improve utilisation of plantation wood. This study demonstrated the economic benefits to the grower in terms of increased log residual value by grading for products rather than to general appearance rules that apply to all products.

5.5.2 Product selection

Sawn products selected for this study (solid timber flooring and laminated panels) were only assumed to produce highest log residual value. Further research into selection of sawn timber products based on product residual values has the potential to improve returns to the grower from the benchmark set in this study. Log physical characteristics according to age, diameter and position in tree, such as density and movement in service, along with product properties such as board thickness, width and length, could each could influence the strategy applied by the sawmiller to maximise value generated from logs. An improved understanding of these could offer opportunities for categorising and pricing logs for greatest returns from them.

5.6 Products and Market Value

Market development for *E. nitens* sawn appearance products is yet to take place. For residual value to be relevant to growers who would invest in a plantation that may not be harvested for decades, product prices would match the future market as well as possible. Investigating product innovations and emerging products along with market potential for products not yet tested in the market is well justified.

5.6.1 Flooring product pricing

The primary target product produced in this case study was solid timber tongue and groove flooring. A global transformation of the solid timber flooring industry is well underway, with approximately half of timber floors laid in New Zealand now engineered flooring product, compared with 68% globally (Robin Curtis, pers. comm. 12/02/2015). Solid timber flooring is losing market share to engineered product because of both price and quality constraints. Well-constructed engineered products can be more stable than solid timber, and installation costs are usually lower (Robin Curtis, pers. comm. 12/02/2015). Given the rotation length of timber plantations and the need for some certainty around markets for resulting products, work is justified in the area of value advantage and economic value to the customer in order to estimate a pragmatic market price for solid timber flooring products based on competition with alternatives.

End matching of timber flooring product has opened up opportunities for reducing wastage and utilising shorter board lengths than in traditional random-length solid timber flooring installations. The trade-off with end matching is that although installation costs and waste are reduced, production costs increase. By deducting the cost of end matching from the graded-pairs >1200 mm price for board lengths 600 mm – 1200 mm, this case study attempted to price short board lengths to a level the market would accept readily. Further work is justified on the opportunity costs involved, to further improve methods for pricing timber products new to market.

Traditionally, timber floors are sanded after installation and before coating, which is an additional cost and generates dust, an inconvenience for the customer. However, sanding may not be required if board lengths were short, edges were perfectly straight and boards were end matched. Installations of solid timber floors are taking place in New Zealand from short end-matched tongue and groove timber that is not sanded before coating (Robin Curtis, pers. comm. 12/02/2015). Such methods offer new to market solid timber products that are potentially competitive with engineered products in both price and quality.

Engineered timber flooring products are available only as shorter lengths, to a maximum of 2.1 m with piece-lengths averaging less than 1 m (Robin Curtis, pers. comm. 12/02/2015). Based on the increasing market share held by engineered product, the appearance of short board lengths in timber floors appears to have gained acceptance in the market. However, there remains uncertainty among merchants and other flooring specialists recently surveyed, who were reticent to the concept of stocking short length solid timber flooring product (Satchell, 2015). A number of merchants surveyed assumed that costs of installation are higher for shorter board lengths compared with longer board lengths and were also under the impression that their customers do not favour the appearance of a floor made from 'shorts'. On average 9.6% of graded sawn flooring timber in this study was between 300 mm and 1200 mm in length, suggesting that accurately pricing this product is important for improving log residual value estimates.

Two survey pricing methods, graded-pairs and constant sum allocation, were employed by Satchell (2015) to estimate prices for *E. nitens* graded flooring lengths between 300 mm and 1200 mm. The increase in price from graded-pairs pricing to constant-sum pricing survey methods for 300-600 mm lengths of clears grade was 100%, suggesting that pricing methods require refinement. However, the graded pairs survey method discounted 300 – 600 mm lengths based on appearance of a floor made from them (Satchell, 2015) and in this case study actual costs of end-matching for 600 mm – 1200 mm lengths and edge-jointing for 300 mm – 600 mm lengths were further deducted for product residual values. In contrast, the constant-sum approach (Satchell, 2015) priced utility and thus respondents' comparative price for different lengths directly. Survey methods that provide the respondent with a greater level of detail on opportunity costs might offer improved accuracy in estimating price.

Pricing 300 – 600 mm lengths edge-jointed as flooring timber is especially problematic because this product is available but new to market. Once the product becomes better established in the market and its price stabilises according to consumer willingness to pay, price estimates would not be necessary and the accuracy with which flooring ‘shorts’ contribute to log residual value would be improved.

Approximately 65% of timber floors are installed over concrete or other solid substrates, with only 35% being laid over timber joists (Robin Curtis, pers. com 12/02/2015). Floors laid over a solid substrate require extremely straight timber in order to be laid tightly, without incurring the additional cost of cramping into place and weighting (Chris Lee, pers. comm. 2014). Short straight lengths, with properly prepared ends, can halve the cost of installation over a solid substrate (Chris Lee, pers. comm. 2014) compared with random length timber that requires docking on-site.

This study quantified product lengths as a straightened product in order to meet the requirements of the progressive section of the contemporary flooring market for perfectly straight boards, as a product potentially competitive with engineered flooring on both price and quality. However, pricing of shorter length flooring products from a market survey of the current population of flooring timber experts (Satchell, 2015) allowed for traditional merchants that exclusively deal with longer-length flooring product to negatively influence the price of shorter board lengths used in this study. This range of views illustrates the state of flux that the hardwood flooring industry is currently in.

Given the range of issues that limit the accuracy with which price of timber shorts can be estimated, further work is justified to reveal the strengths and weaknesses of competing products and their associated opportunity costs. Improved price estimates for emerging flooring products are well justified in order to increase confidence in estimated grower returns from plantation *E. nitens* based on the residual value approach.

5.6.2 Panel product pricing

After taking into account the costs of glue-laminating and sale price on residual laminated product value, panel feedstock performed very well in terms of price by volume. This illustrates the significance with which selection of products and adding value to raw materials determines log value. If this product were to gain market share, logs with a smaller diameter than those milled in this study could potentially be utilised profitably for laminated appearance products. The primary constraint to milling smaller logs is increased production costs as log diameter decreases. By including sawmilling costs, the residual value approach offers the opportunity to explore utilisation of smaller logs in conjunction with market research that defines price and demand for these products.

5.6.3 Slab firewood

Significant volumes of slabwood (over half of the total log volume) were produced from the case study sawmilling operation and firewood by-product was produced at low cost as part of the sawmilling operation. Predicted revenue per hectare from slabwood firewood was $17,950. *Eucalyptus nitens* has been extensively planted in the Canterbury plains for firewood (P. Milne pers. comm. 2014) and is recognised as differentiated and superior to radiata pine. Producing this level of income from a by-product at little cost clearly improves the economic viability of growing *E. nitens* for solid timber in Canterbury, with the region's strong demand for firewood. In other regions short fibre pulpwood might have higher value than firewood and both slabwood and logs too small for sawing are suitable for pulping.

5.7 Processing and Scale Efficiency

An emerging plantation forestry species is likely to be harvested initially as a small resource, but with growth expected over time. This study was intended to evaluate a small scale processing operation as a benchmark from which cost efficiencies could be improved with scale.

The small solar kiln with its high capital cost contributed significantly to high drying costs of $202.28 per nominal sawn cubic metre. This is double the cost for drying ash eucalypt in Australia (G. Pearn, pers. comm. March 2015). Total processing costs of $624 per nominal sawn cubic metre before accounting for sawmill overheads undoubtedly could be improved with increased operating scale. Lower costs would directly improve log residual value. If processing scale were increased and revenue maintained with a corresponding reduction in processing costs, log residual value and NPV to the grower would very likely be significantly improved.

5.8 Sawmill Profit

Management, marketing and sawmill profit as an overhead cost could not be measured and accurately assessed within the budget and scope of this study. An 8.5% return on investment of capital and equipment along with depreciation costs for equipment may not be sufficient to justify owning and operating an enterprise buying logs, processing these and selling the sawn products. The additional return of 10% of sawn timber revenue used in this study was arbitrary. Profit over and above return on investment that would sustain an operation is dependent on the individual proprietor's expectations and would likely be commercially sensitive. However, a reasonably accurate profit margin could be estimated using empirical methods and further work may be justified to improve overhead cost estimates for applying the residual value approach to profitability of growing *E. nitens* for solid timber.

5.9 Conclusions

The short rotation length and high productivity of *E. nitens* is appealing to growers and if drying degrade issues could be further overcome from those measured in this study the species would undoubtedly hold commercial promise, given the good physical wood properties and appealing appearance of the wood. This case study indicates that *E. nitens* does have promise as a commercially profitable plantation forestry species for production of solid timber products. However, more work is justified to improve the accuracy of predictions.

5.9.1 Residual value method

The residual value method offers opportunities to appraise log values in the absence of market prices for the products being produced. However, credibility of results determined using the residual value method could be undermined unless price estimates are sufficiently accurate to satisfy the grower speculating on a long term return on investment. This study attempted to price products as willingness to pay within a progressive market sector to achieve that goal. Further work in this field to improve methods is justified.

Board width, levels of degrade, board length, board grade and physical properties are all factors that contribute to product price and therefore revenue from the log. These factors together with log diameter and position could emerge as significant predictors of log revenue and therefore price in the market.

5.9.2 Sawn recoveries

The sawmilling methods used in this case study produced adequate sawn and grade recoveries that justify further attention to be given to the commercial potential for solid timber production from *E. nitens*.

The well pruned case study trees yielded high recoveries of clearwood from buttlogs but drying degrade reduced product recovery of clearwood. Thinning of the case study stand produced sufficiently large diameters to harvest the stand at 15 years old and this regime was estimated to provide an adequate return on investment to the grower. Thinning regime could be improved to target diameters that offer optimum processing efficiency.

Avoidable defect was minimised and grade recoveries were maximised by best practice methods as identified in the literature. Log revenue was quantified using price estimates for the timber products produced and costs were minimised as much as practicable using the case study equipment. Resulting log residual values reflected current best practice as a benchmark from which improvements would increase profitability for the grower.

Log length and sawn timber green thickness were appropriate for mitigating processing issues that could otherwise cause serious degrade. Log length could potentially be further optimised to diameter. Board thickness was not adequate to avoid skip on profiled surfaces caused by collapse on boards from some buttlogs. Further work is justified to examine costs and benefits from increasing green board thickness in buttlogs if steam reconditioning were not practiced.

Minimising the delay between harvesting and sawmilling, along with applying sawcuts that released stress and excluded pith ensured that defect in dry boards caused by end splits was managed to levels that did not significantly impact on profitability.

Product value was high per log cubic metre of input and per sawn cubic metre. Costs were also high but the resulting return on investment for the grower was adequate and indicates that it may be profitable to grow *E. nitens* for production of solid timber in Canterbury.

5.9.3 Net present value

In addition to log price, primary drivers of profitability were land price and harvesting/transport costs. Land price and harvesting/transport costs trade off against each other and high harvesting/transport costs may be too excessive to justify a low land price.

Log price was most influenced by sawn timber revenue, drying costs and level of sawmill profit. Drying costs and grade recoveries along with product price estimates contributed to sawn timber revenue, from which an estimate of sawmill profit was deducted for log residual values. Because so many variables are involved with predicting profitability and these each would likely vary from the base estimates in this case study, scenarios that illustrated the sensitivity with which each of these factors influenced return on investment were necessary. These showed how much returns could vary from the base scenario. In this case study *E. nitens* was harvested on a relatively short rotation for solid timber, was highly productive and produced grade recoveries that resulted in log price estimates that indicated a profit for both grower and processor. The next step is to improve methods used for predicting *E.*

nitens log residual value to provide growers with more definitive predictions of log values suitable for modeling profitability from stand data.

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Appendix A :
Costs and Assumptions

Discount and interest rate: 8.5%

Costs do not include GST

A 1: Grower Costs

Annual growing costs:

Rates $424 per hectare.

Insurance $10 per hectare.

Management $50 per hectare.

Land rental: $850 as annual interest on land value of $10,000 per hectare.

One-off growing costs:

Site preparation cost $200 per hectare, year 0.

Seedlings cost $1000 per hectare, year 0.

Planting cost $300 per hectare, year 0.

Releasing cost $200 per hectare, year 1.

Pruning costs $1500 per hectare, year 3.

Pruning costs $800 per hectare, year 4.

Pruning costs $200 per hectare, year 5.

Thinning cost $800 per hectare, year 8.

Logging and loading*:

- Base scenario: $28 per tonne (assumed "easy to flat" terrain).
- Easy Hill: $31 per tonne.
- Moderate steep: $38 per tonne.

Transport cost*:

- Base scenario: $16 per tonne (50 km).
- 100 km: $27 per tonne.
- 150 km: $39 per tonne.

*From Laurie Forestry website http://www.laurieforestry.co.nz/Pricing-Table

A 2: Product price assumptions

Firewood price, wholesale: $50 per thrown cubic metre.

Firewood conversion factor: One cubic metre by volume = two thrown cubic metres.

Firewood log price, delivered: $50 per cubic metre (J. Fairweather, pers. comm. July 2014).

Pulpwood price, Southland: Stumpage $20 or better per tonne for chipwood feedstock. Landed at mill $75 per tonne (Graeme Manley, pers. comm. February 2015).

Sawdust price: $25 per cubic metre.

Sawdust conversion factor: 230 kg per cubic metre.

Flooring timber Reference Product (Victorian ash) wholesale price for 125 mm nominal width, select grade, lengths longer than 1.2 m: $4.09 per lineal metre.

"The current price NZ wholesalers pay for 108 x 19 Victorian Ash T&G flooring Select grade A$3.79/lm landed in NZ." (Brett Bould, Pers. Comm. 20 May 2014). 1AUD=1.07812NZD @ 20 May 2014.

A 3: Product residual values

Laminated benchtops:

Nominal 75 mm x 25 mm = 60 mm x 19 mm finished. 3 m long panel, 650 mm wide, 60 mm thick =0.117 m^3

Nominal 50 mm x 25 mm = 40 mm x 19 mm finished. 3 m long panel, 650 mm wide, 40 mm thick =0.078 m^3

19mm widths = 35 pieces for 650 mm wide benchtop panel.

Costs for graded and blanked product: Marking for layup and block stacking: 3 hours per cubic metre, secondary labour.

Transport both ways for laminating: $100 per nominal cubic metre.

Laminating cost $1200 per cubic metre of product.

Value per cubic metre is the same for 40 mm thick and 60 mm thick panels.

Non- buttjointed panel:

Feedstock profile: board length >1500 mm, graded and blanked.

Grades: FFT Panel Laminating Clear One Face, FFT Panel Laminating Clear Two Faces, FFT Clear Joinery.

Retail value of 6omm thick panel: 3 m long, 650 mm wide = $500+gst (J. Fairweather sales, October 2014).

Wholesale price less 30% = $4,487 per cubic metre of product.

Value per lineal metre 75 mm nominal: $5.12

Residual value per lineal metre 75 mm nominal board: $3.56

Value per lineal metre 50 mm nominal: $3.41

Residual value per lineal metre 50 mm nominal board: $2.38

Buttjointed panel:

Feedstock profile: board length 300 mm - 1500 mm, graded and blanked.

Grades: FFT Panel Laminating Clear One Face, FFT Panel Laminating Clear Two Faces, FFT Clear Joinery.

Retail value of 6omm thick panel: 3 m long, 650 mm wide = $350 (J. Fairweather sales, October 2014).

Wholesale price less 30% = $3,141 per cubic metre of product.

Value per lineal metre 75 mm nominal: $3.58

Residual value per lineal metre 75 mm nominal board: $2.03

Value per lineal metre 50 mm nominal: $2.39

Residual value per lineal metre 50 mm nominal board: $1.35

A 4: Flooring timber residual value

Edge jointing: $300 per cube for jointing (100-150mm widths, 200-700mm lengths, blanked with two straight edges and two flat faces and squared ends). Preparation costs assumed to be $100 per cubic metre based on $16-$17 / hour, 4-5 hours for a cube of shooks. Jointed lengths usually 3.6, 4.2 or 6.3 (cladding). 700 max lengths because of feeding systems and possible crook.

End-matching: Cost $45/hour approximates to $170/nominal cubic metre (Robin Curtis, pers. comm. 26/9/14)

Plus markup of 30% = $221 per nominal cubic metre.

For comparison: Random block-cutting costs (300-600 mm blocks): 80 lineal metres per hour, $0.25 cents per lineal metre.

A 5: Production costs

Management and overheads:

A processing, marketing and management overhead cost for the case study processing operation was calculated as 10% of sawn timber revenue.

Sawmill costs:

Log handling: 30 logs per hour.

Electricity: Cost per hour = $3.69

Ten units per hour of operation, Daily rate = $1.20, plus rate per unit = $0.22 (Prices from November 2013 account).

Petrol: Cost per hour = $4.02

Edger uses 20 litres of petrol in 560.5 minutes of operation. Price $1.88 excluding gst (January 2014, source http://www.aa.co.nz/cars/motoring-blog/petrolwatch/january-2014-petrol-and-diesel-prices/).

Diesel: Cost per hour = $2.80

Band sawmill uses 20 litres of diesel in 560.5 minutes of operation. Price $1.31 per litre excluding gst (January 2014, source http://www.aa.co.nz/cars/motoring-blog/petrolwatch/january-2014-petrol-and-diesel-prices/).

Lube oil, cost per hour $0.76

6 litres of lube oil are used in 560.5 minutes of operation. Price $1.18 per litre.

Bands:

Cost for band = $60

Band sharpened 5 times before replacement.

Two hours service between sharpening.

Sharpening cost $20 (i.e. $10 per hour).

One blade change was assumed to take place (4 minutes) every 2 hours for primary labour unit, while the secondary labour unit continues edging.

Edger blades: Sharpened every 1000 hours, one hour to sharpen (Primary labour).

Sawmill machinery:

Rental as interest on capital investment plus depreciation:

Interest rate: 8.5%

Woodmizer LT 40: $34,783, depreciation 13% straight line.

Woodmizer twin-blade edger: $8,700, depreciation 13% straight line.

Firewood cutter: $4347.83, depreciation 13% straight line.

Electricity setup costs $10,000, depreciation 5% straight line.

Belts, rollers: $1739.13, depreciation 13% straight line.

Extraction fans: $2608.70, depreciation 13% straight line.

Loader $5,000, depreciation 20% straight line.

Site rental:

Land value $20,000 per hectare, interest 8.5% per annum.

Rates $300 per hectare per annum.

Site = 1/4 hectare.

Labour:

Labour: Primary $30 per hour (gross, including holiday pay).

Labour: Secondary $20 per hour (gross, including holiday pay).

Sawmill annual operating hours: Assuming 229 work days per year, 4 weeks holiday, 52 Weeks times 5 days a week = 260 days.

Less 20 days annual leave = 240 days.

Less 11 days statutory holidays = 229 Days a Year. At 8 hours per day that is 1832 hours. Allowing for 95% sawmill work time the time the sawmill is operating was calculated as 104424 minutes per annum.

Repairs and maintenance:

Repairs and maintenance: $1260 per annum, or $0.69 per hour for 1832 operating hours per year. Repairs and maintenance labour was also allowed for as an additional hourly cost of 2% of total wages.

A 6: Drying costs:

1 stack = 1.0177 nominal sawn m^3 timber.

Shifting stack from sawmill into drying position: 4 minutes primary labour, $1.97 per cubic metre.

Stack preparation (weighting and wrapping): 10 minutes primary labour to put weight on two stacks (i.e. 5 minutes per stack) and 10 minutes secondary labour to wrap one stack.

Drying shed (for shed air drying): $30,000. Depreciation 3% straight line.

Capacity of 24 stacks of sawn timber.

Yard drying space (for yard air drying): $6600 for digger and $1000 for gravel

Capacity for 200 stacks. Depreciation 20% straight line. Assume 1 year drying average.

Cloth wrap: $1.30 per square metre. Each stack requires 16 square metres of microklima (wrapped twice) and the microklima can be used 3 times. http://www.easytek.co.nz/downloads/BirdNetting.pdf, includes gst for orders over 400 square metres.

Concrete weights: $200 each (these weight 2 stacks each), depreciation 5% straight line.

Drying pallets: $40 each, depreciation 20% straight line, one pallet per stack.

Fillets: $0.39 each, 7 fillets per row, 17 rows per stack.

Total drying costs for yard drying: $202.28 per nominal sawn cubic metre.

Total drying costs for shed drying: $231.66 per nominal sawn cubic metre.

Solar kiln:

Solarola Mini-Pro $6m^3$ Sun Dry kiln: $29,058 cost, depreciation 5% straight line.

Annual capacity 36 m^3.

Forklift:

Forklift cost and site rental cost were based on the solar kiln capacity.

Forklift: $3000, depreciation 20% straight line.

Steam reconditioning cost assumed to be $30 per nominal cubic metre.

Site rental:

Land value = $20,000 per hectare, interest 8.5%.

Rates = $300 per hectare.

Site = 1/2 hectare.

Repairs and maintenance:

5 minutes per nominal sawn cubic metre.

A 7: Processing costs

Shifting stack from kiln into processing shed: 5 minutes, primary and secondary labour units.

Labour, blanking: 65 boards per hour (195 lineal metres), secondary labour.

Labour, profiling: 60 boards per hour (180 lineal metres), secondary labour.

Grading and docking: One board per minute, docked and graded, secondary labour.

Block stacking: 1000 boards per hour (secondary labour).

Despatch and preparation: 1000 boards per hour (secondary labour).

Knives: All 4 edge knives cost $25 to sharpen and all 4 face knives cost $30 to sharpen. These knives need sharpening every four m3 but each board passes through machine twice.

Electricity: 6.5 kw per hour (blanking or profiling) which includes extraction fan. Two passes per board at 60 boards 3m long per hour. Daily rate $1.20, plus rate per unit $0.22 (Prices from November 2013 account).

Boron treatment: $29.76 per nominal cubic metre. A$ 26/m3 from page 27 Forestry Tasmania technical report 08/213, August 2013 (1AUD=1.1448 NZD on 28 Aug 2013).

Processing shed rental: $52,000, depreciation 20% straight line per annum.

Logosol PH 260 four sider: $9,130, depreciation 20% straight line per annum.

Docking saw: $700, depreciation 13% straight line per annum.

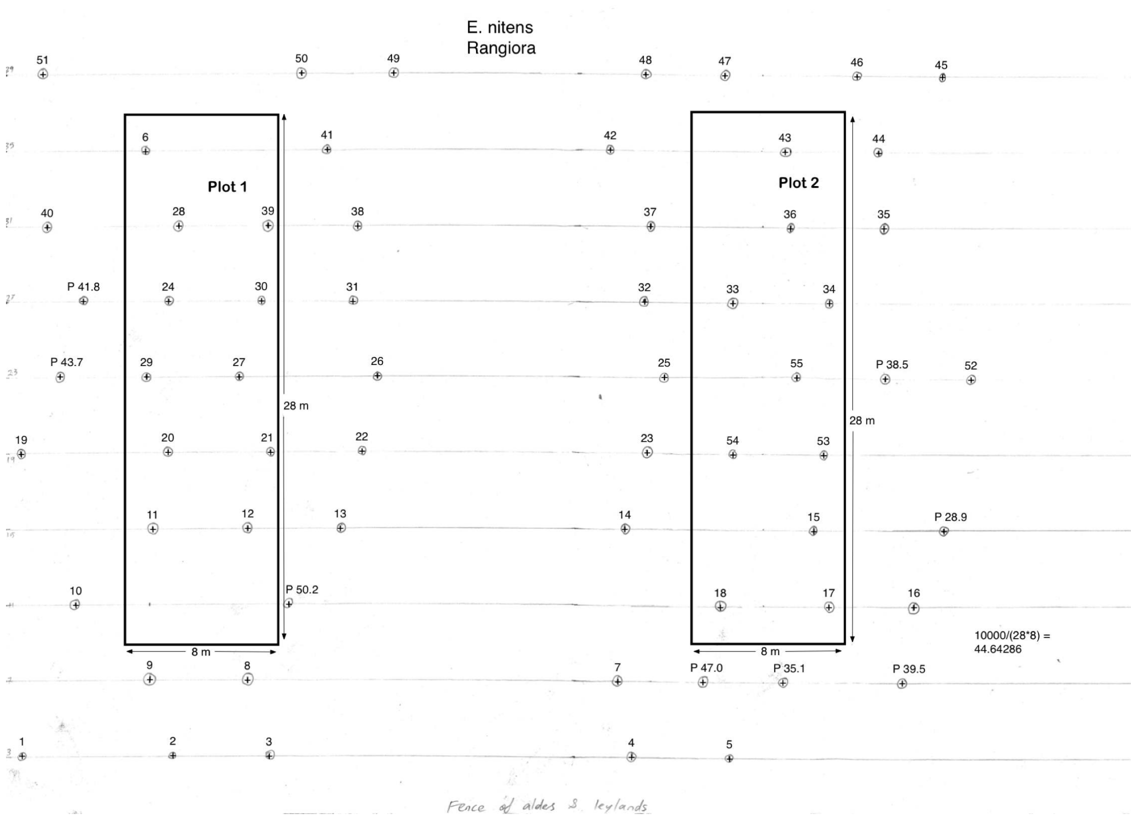
For Comparison:

Profiling costs 45 cents per lineal metre and is charged out as $0.90 per lineal metre (Robin Curtis, pers. com 12/02/2015).

End-matching costs 45 cents per lineal metre and is charged out as $0.90 per lineal metre (Robin Curtis, pers. com 12/02/2015).

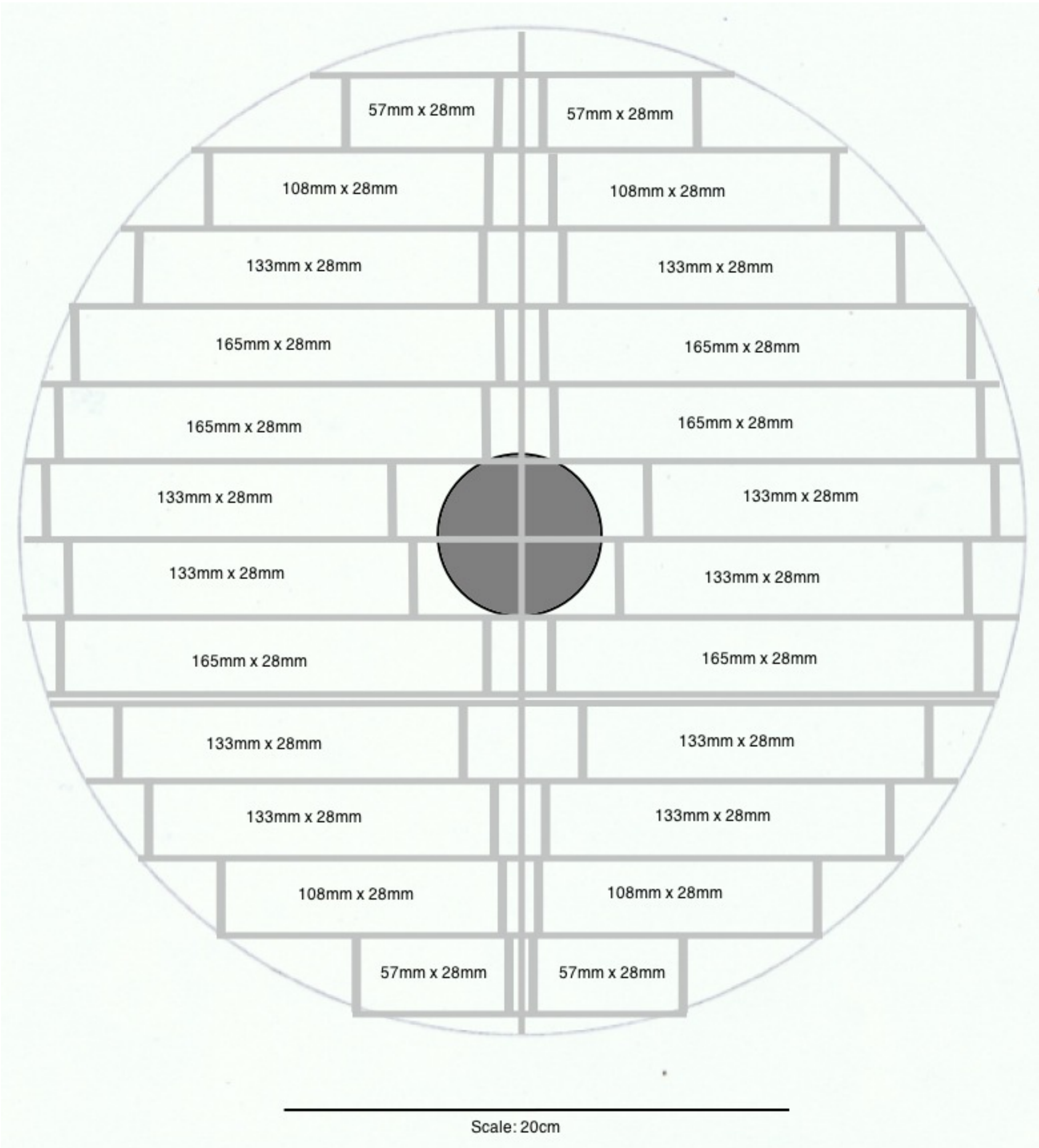
Appendix B :

Scale Diagram of Case Study Stand and Plots



Appendix C : Sawmill Pattern

Example sawmilling pattern: 40 cm diameter log



Appendix D : Sawn timber prices

Table 35
Wholesale Prices for Flooring Profiles, Graded-Pairs Comparison Pricing

Board Profile	Length 300 – 600 mm	Length 600 -1200 mm	Length >1200 mm
100 mm Width Select/Clears Grade	$1.15	$2.54	$2.96
100 mm Width Standard Grade	$0.77	$2.07	$2.49
100 mm Width Feature/High Feature Grade	$0.44	$1.65	$2.08
125 mm Width Select/Clears Grade grade	$1.86	$3.44	$3.86
125 mm Width Standard Grade	$1.37	$2.82	$3.25
125 mm Width Feature/High Feature Grade	$0.94	$2.28	$2.70
150 mm Width Select/Clears Grade	$2.69	$4.48	$4.91
150 mm Width Standard Grade	$2.07	$3.70	$4.13
150 mm Width Feature/High Feature Grade	$1.52	$3.01	$3.44

Table 36
Wholesale Prices for Flooring Profiles, Constant-Sum Allocation Pricing

Board Profile	Length 300 – 600 mm	Length 600 -1200 mm	Length >1200 mm
100 mm Width Select/Clears Grade	$2.30	$2.58	$3.04
100 mm Width Standard Grade	$1.98	$2.26	$2.72
100 mm Width Feature/High Feature Grade	$1.65	$1.93	$2.39
125 mm Width Select/Clears Grade grade	$3.09	$3.44	$4.02
125 mm Width Standard Grade	$2.69	$3.04	$3.61
125 mm Width Feature/High Feature Grade	$2.27	$2.62	$3.20
150 mm Width Select/Clears grade	$3.89	$4.31	$5.00
150 mm Width Standard Grade	$3.40	$3.83	$4.52
150 mm Width Feature/High Feature Grade	$2.91	$3.33	$4.02

Table 37

Wholesale Prices for Panel-Laminating Profiles as Residual Values

Board Profile	Length 300 – 1500 mm	Length >1500 mm
50 mm Width	$1.35	$2.38
75 mm Width	$2.03	$3.56

Appendix E : Glossary of Terms

AS: Australian Standards 2796.1

Backsawn: See flatsawn.

Blanked: Dressed through a four-sider to dimensions approximately half way between green and fully profiled size.

Box: Defect caused by natural feature in the tree such as large knots, bark-encased knots, kino, discolouration, decay etc.

Bow: The lengthwise curvature of the broad face of a piece of sawn timber.

Cant: Segment of a log that has been sawn on two or more faces to give final product width, but which requires further resawing to produce final thickness-dimensioned material.

Checking: Either of internal or surface checking.

Clears: Highest Farm Forestry Timbers grade, equivalent to Australian Standards select grade.

Clearwood: Wood devoid of defect or feature that lowers the grade.

Collapse: Excessive and uneven shrinkage causing corrugation of the wood surface. Characterised by a caved-in or corrugated ("washboarded") appearance of the wood surface. Flattening of single cells or rows of cells takes place during the drying or pressure treatment of the wood.

Concealed surface: The surface that is not exposed in a product (e.g. the underside of a floor board or bench top).

Corewood: Wood adjacent to and including the pith of the tree that is defective either because of decay, stress fractures or other causes that affect the physical performance of the wood. In this study distinguished by colour on the freshly sawn surface.

Crook: The lengthwise curvature of the edge of a piece of sawn timber.

Cross cutting: The cutting of a tree trunk into logs.

Degrade: Feature that lowers the grade and therefore price of the wood.

Defect: Feature that does not meed grade requirements.

Docking: Cross cutting of boards into board pieces.

Dressing: Planing the surface of the wood to be smooth.

Edge-jointing: Finger jointing so that fingers are seen on the edge of the board but not the face. The joint seen on the exposed face is a line tangential to the edge of the board.

End-matching: Lumber that is end dressed and shaped to make a tongued-and-grooved joint at the ends when laid end to end.

Exposed surface: The surface graded for appearance.

Face cut: An undimensioned cut which is used to produce a straight face.

Feature: Distinctive natural and contrasting pattern inherent in timber.

Feature grade: The lowest Farm Forestry Timbers grade, equivalent to Australian Standards high feature grade.

FFT: Farm Forestry Timbers grades.

Flatsawn: Timber is flatsawn (or backsawn) if the growth rings as seen from the end section meet the face of the board at an angle less than 45^{o} with the board face.

Flitch: A large piece of sawn log intended for further cutting. A flitch may have two or more sawn edges but is not sawn to final dimension.

Grade sawing: Sawing for maximum recovery of high grade boards that are suitable for specialty uses.

Green size: The size the board was sawn to.

High feature grade: One of three grades used in Australian Standards AS 2796.1. Equivalent to FFT feature grade.

Internal checking: For the purposes of this study "internal checking" is defined as where the check goes in from the surface more than 2mm on the 19mm profiled product on the cross section surface, or where the checks are inside the edge of the cross section surface.

Knotty core: The area of the log within the pruning wounds.

Nominal size: Size by which timber is known and sold in the market. The named size, which may vary from the actual size once dressed as a final product.

NPV: Net present value.

Price-size-gradient: The gradient whereby price per cubic metre increases or decreases according to log volume.

Profiled surface: The machined or dressed surface that is planed into the size and shape required for the final product.

Quartersawn: Boards sawn so that the annual rings, as seen from the end-section, form an angle of not less than 45^{o} with the board face.

Residual value: The theoretical maximum amount the processor would pay for the log or product. Processing costs and required profits are deducted from the total price of the derived products.

Short: Short piece of sawn timber.

Slab: Timber that has been dimensioned to thickness but not width.

Slabbing: The process of cutting slabs, i.e. cutting faces for a sized thickness but not edges.

Select grade: Highest Australian Standards AS 2796.1 grade, equivalent to Farm Forestry Timbers select grade.

Skip: An area that failed to dress.

Spring: See crook

Standard grade: The next grade below select or clears grades.

Straightening cut: A second cut that straightens a board or flitch that previously curved from deflection.

Surface checking: For the purposes of this study "surface checking" is defined as either shallow checks that are seen on the surface of rough sawn timber and do not necessarily dress out on profiling, or checks less than 2mm deep and less than 1mm wide on the 19mm profiled surface.

Strip floor: A tongue and groove floor laid over joists.

Tare: The weight of the truck carrying the logs.

T&G: Tongue and groove profile.

Wane: The absence of square wood on the edge of a board indicated by the underbark surface.

Want: Mechanical damage, including chipping damage caused by dressing the material.

Washboarding: The shape of the board surface resulting from uneven shrinkage caused by collapse.